Tasmanian bat ecology:
Conservation of native fauna

By

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Abstract

Conservation of biodiversity is one of the most important issues globally. Chiropteran fauna contributes one quarter of mammalian species but little information is known about most species. Tasmania has eight known species of bats including one endemic species, *Nyctophilus.sherrini*. There have been a number of studies conducted in Tasmania, yet much of the biology and ecology of most species remains unclear. Effective conservation of local biodiversity requires scientific information such as distribution, habitat relationships, and feeding behaviours.

The present study contributes new information about the distribution for most species in Tasmania by using Anabat detector systems. Identification of species by their echolocation calls sampled from free flying individuals was achieved, by developing a regional key derived from trapped bats and an automated identification program, Anascheme. Six species/species groups were successfully distinguished by the key.

Distribution records were gathered by echolocation recordings and the key newly developed for the study. I found that most sites have high bat species richness, as more than four species were recorded at the majority of sites. Three *Vespadelus* species were the most commonly observed and the Southern Forest Bat, *V. regulus*, was recorded at 100% of sites. In contrast, the high-flying Eastern Falsistrelle, *Falsistrellus tasmaniensis*, was only present at only 17% of sites.

Species-habitat relationships were analysed where possible. Tasmanian bats appeared to have less species-specific requirements in their preferred activity areas. In addition to spatial partitioning of niches, the possibility of discrete temporal activity patterns of species was examined. Calls recorded for each species were assigned into 10 equal-time intervals between sunset and sunrise. There were no significant differences in a total activity index between time intervals by species, suggesting a high level of activity throughout the night. Evidence of a weak bimodal pattern in nightly activity was recognised in several species. Emergence timing was also compared between species, and *F. tasmaniensis* was shown to have a significantly later emergence time, and thus later peak activity timing than the others. Although analysis detected no significant effects of weather conditions on different observation nights, nightly fluctuations in the activity of several bats were apparent.

Average mergence timing was used to derive a species accumulation curve. This is a useful tool for estimating the minimum time effort required to prepare a species inventory. I found that that the species accumulation rate is similar to the reported for the Victorian (Australia) bat fauna and less similar than that for tropical Australian bats. At least three and half hours of echolocation call sampling per night is necessary to collect a satisfactory sample suitable for estimating the local inventory of Tasmanian bats.

Some conservation implications for the Tasmanian bat fauna were drawn from my study and from previous work. Better protection of forest habitats that provide sufficient roost opportunities is a primary objective, as well as the retention of hibernation sites as all species hibernate during the winter months. The present study collected data during the austral summer, similar to most previous studies, suggesting that a better understanding of hibernal activity is required for Tasmanian bats.

In conclusion, much more research is required to better understand the biology and ecology of the Tasmanian bat fauna to conserve bats across the diverse landscapes which make up Tasmania.

Statement of Originality

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

Authority of Access

This thesis may be made available for loan and limited copying in accordance with the Copyright Act 1968.

Statement of Ethical Conduct

The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

Masato Inada

Date / / .

Table of Contents

List of Tables

List of Figures

Chapter 2

Chapter 3

Chapter 4

Glossary

Call characteristics: parameters that are species- unique and can be used as measurement of identification

Call file: with Anabat system, a recorded call is saved as a digital file. An assumption is that a file contains a call sequence of an individual lasting maximum 15 seconds. In reality, the file can be made of several different individuals but at any given time only the strongest sound signal is recorded, and other signal information is lost while transforming data.

Call parameter: or attributes which can be typical to species echolocation call. Different sound analysis (i.e. bat detector types) can produce or extract different aspect of characteristics from the signal

Call phase: call sequence can be divided into three phases; Search phase; prey locating/discriminating phase; and feeding buzz/terminal phase.

CF call: constant-frequency call. Signal does not contain distinctive changes in frequency.

Doppler shift: sound frequency change brought about by movements of sound source and sound detector. Received frequency sifted to higher when both objects are moving closer, and the frequency sifted downwards as they moving away. Echolocating bats need to compensate the change in the frequency drought about Doppler Effect while flying by either Doppler-sift compensation (i.e. CF bats) or emitting broader frequency range (i.e. FM bats)

Echolocation call: bat call consists of repetitive, high frequency signals exceeding human audible range over 20 kHz, suggested primarily used for orientation during flight in aid of visual. Calls such as distress call and social calls are normally excluded as these call are used mainly communications. A call may, as often, contain different signal patterns and call phases**.**

Echolocation type: echolocation call types is defined by feature of signal shapes, and generally categorised into 3 groups; FM (Frequency-Modulated); QCF (Quasi-Constancy-Frequency) and; CF (Constant-Frequency). Majority of bats use a combination of FM and QFM.

Feeding buzz: typical in most of insectivorous bats when catching insect. When bats come to contact prey, they change call structure from search phase to higher frequency, shorter repetitive phase. It is obvious and easier to recognise when a call involving both phases, yet only feeding buzz was recorded can be confused with other species echolocation call.

FM call: frequency-modulated call. Frequency of a signal changes within duration.

Harmonics: signals normally have several harmonic signals at the same moment. When base frequency is expressed as N (base harmonic), second is 2N, third is 3N and goes on. Anabat system, unfortunately, lose harmonics as using zero-crossing analysis.

Hibernacula: roosts used particularly for hibernation during winter in temperate bats. Requirements for suitable hibernacula may be different from roost requirements.

Hibernation: Often misinterpreted as "prolonged torpor". The status of hibernation is not the same as torpor by dropping body temperature as low as a couple degrees above freezing point. General mammalian hibernation features with arousal bouts during hibernation especially in natural environment. Arousal from hibernation takes longer duration the body temperature to reach sufficient warmth than torpor, sometime may need external heat.

Pass: in acoustic survey based on bat detector each call sequence, or call files, are assumed to represent an individual passing. As bat detectors cannot distinguish individual bats, number of passes is considered an indicative parameter of amount of activity. With Anabat system, each call file is defined represent a pass of an individual bat regardless of length of file or actual number of bats recorded in the same files.

QCF call: quasi-constant-frequency call. Frequency of a signal changes within duration, but it contains distinctive flat part in between changes.

Roost: equivalent to nest for other animals. Day roost is a primary roost which bats spend most of time during day time. Night roost represents a site to rest temporally during night used for handling large prey and digesting it.

Signal: synonym of pulse, call signal. It is a basic component of a call. A signal can be different in terms of shape, duration, frequency and etc. the difference is assumed rather species-specific and is important measurement of acoustic identification.

Torpor: relatively shorter period of which body temperature is dropped. Body temperature stays in a range of thermo neutral zone (TNZ). Normally occurs during day time and generally the term used to express the sleeping.

Ultrasound: sound that is consisted of higher frequency than human audible range. The upper frequency human can "hear" is limited to 18 kHz to 20 kHz. Ultrasound normally indicates sound frequency above 20 kHz. Most of echolocation calls are inaudible, with few exceptions.

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I'd like to thank the persons whose helps and supports kept me going during the course of this study. This project was only made possible with help from many people, and I would like to acknowledge the following for their time, support, and expertise.

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Chapter 1

General Introduction

1.1 Introduction

All bats belong to the mammal order Chiroptera which consists of two suborders; the Megachiroptera (fruitbats/flying foxes) and the Microchiroptera (microbats). Bats contribute one quarter of the total number of mammalian species with over 1100 species recognized globally, and a few new species are recognised every year (Fenton, 2003; Funakoshi *et al.,* 2007; Churchill, 2008). Bats are the most widely distributed and the second largest mammalian order only outnumbered by the Rodentia. Bats are thought to be the most diverse group of mammals in terms of their behaviour, morphology, distribution and diet. Bats are collectively worldwide in their distribution and are only absent from the Polar Regions. Body size in bats spans three orders of magnitude, from less than 1.5 grams (*Craseonycteris thonglongyai*) to over 1.5 kilograms (*Pteropus vampryus*) (Fenton, 2003; Funakoshi *et al.*, 2007).

Although 70% of bat species are insectivorous and insects are the predominant food resource for a majority of temperate species, the diet of bats in tropical regions consists of a wide variety of items; pollen and fruit, fish, other animals including other bats and blood.

Currently 77 species make up the Australian bat fauna, and 20% of them are endemic to the continent (Churchill, 1998; Mickleburgh *et al.*, 2002; Churchill, 2008). The Australian continent provides a wide range of habitats from tropical to cold temperate climates, coastal heath, temperate rainforest, and inland desert. Such environmental diversity requires bats to develop some degree of specialisation to their niches. Tasmanian bat population represent the southern limit of bat distribution in Australia (Dixon & Rose, 2003).

1.2 Studies on the biology, ecology and ecological roles of bats

An increasing number of studies on bats worldwide use the new technology of ultrasonic bat detectors for surveys. Identification of bat species by their echolocation calls can vary in accuracy between taxa, as well as detector types (e.g. Obrist, 1995; Barclay, 1999; Hayes, 2000). However species identification using quantitative analysis of calls has been successful in many areas including Europe (e.g. Mayer & von Helversen, 2001; Ridgwell *et al.,* 2009), Central America (e.g. Rydell *et al.,* 2002; Macias *et al.,* 2006) and Australia (e.g. Woodside & Taylor, 1985; Herr *et al.,* 1997; Law *et al.,* 1998, Wilson, 2003; Pennay *et al*., 2004).

Echolocation methods are now the primary means of data gathering for species inventory and discovery of new species (Fullard, 1989; Walsh & Harris, 1996; Milne *et al.,* 2003; Ford *et al.,* 2005); habitat use of species (Sherwin *et al*., 2000; Gannon *et al.,* 2003; Law & Chidel, 2006;); foraging activity (Neuweiler, 1989; Barclay & Brigham, 1994; Fenton & Griffin, 1997); temporal activity patterns (Hayes, 1997; Humes *et al.,* 1999; Milne *et al.,* 2004; Scanlon & Petit, 2008); and habitat evaluation by bat activity (Wang *et al.,* 2003). Data is also used to developed habitat or distribution modelling (e.g. Jaberg & Guisan, 2001; Greaves *et al*., 2006; Milne *et al.,* 2006; Frick *et al.,* 2008).

Despite their local abundance, relatively little is known about most bats at species level. Generally speaking, bats are ubiquitous in the terrestrial ecosystems of the world and particularly diverse and abundant in the tropics (Medellin *et al.,* 2000; Fenton, 2003). Because of the dramatic ecological and evolutionary radiation of bats, they occupy every trophic level where they select specific habitats, in many cases based upon particular ecological niches (Medellin *et al.,* 2000). Bats play important roles in some ecological processes involving seed dispersal, pollination, and insect population regulation (e.g. Yalden & Morris, 1975; Findley, 1993; Medellin *et al.,* 2000; Funakoshi *et al*., 2007). In this sense, bats may be suitable indicators to evaluate habitat degradation as they are highly mobile and K-strategists. Their distribution and abundance can be expected to vary markedly in response to abiotic or biotic factors affecting key population demography variables in the long term, and spatial positioning within the landscape in the short term (Walsh & Harris, 1996; Fenton, 2003; Wang *et al*., 2003).

1.3 Information required for the conservation for bats

The importance of bats to biodiversity, ecological and economic value to ecosystems, and vulnerability to decline makes monitoring trends in their populations a cornerstone for their future management (O'Shea *et al.,* 2003). Bats are one of the most difficult groups of wildlife to study, and there is a lack of basic knowledge about biology and habitat ecology for most of species of bats, including details of roost use, foraging areas, population dynamics, and response to management (Arnett, 2003; Fenton, 2003).

Lack of information makes assessing the status of species difficult, which in turn hampers the development of appropriate conservation measures. For example, currently there is no established means for determining trends in population at larger scales and appropriate approaches for estimating abundance of forest-dwelling species do not exist (Arnett, 2003). Even though a quarter of total bats species are listed in the IUCN Red List as threatened (Mickleburgh *et al*., 2002; IUCN, 2009), taxonomic uncertainties have been highlighted in the Australian bat fauna where the status of many taxa remained unsettled. This makes conservation planning even more difficult (Law *et al.*, 1999; Mickelburgh *et al.*, 2002).

Recognition of bats' roles in ecosystems and their potential to be indicator species has drawn attention to their conservation and management. Yet to make informed management decisions at the community level requires considerable information such as baseline species inventory (Johnson & Gates, 2008). Species inventory in a defined region is especially important information. General assessment of baseline inventories can be made from previous records only where intensively studied or long-term collections of species composition data are available. Target areas need to be thoroughly sampled to make informed management decision regarding bats. Aforementioned Tasmania represents the southern limitation of Australian species. A baseline inventory can be especially useful in areas located on peripheries of previously known geographic ranges of species (Johnson & Gates, 2008).

Temporal and spatial variations in distribution must be addressed in order to fully understand how bats respond to their surrounding environments. Distribution and composition of species can change over time and long term monitoring must be implemented to document this. For conservation purposes, adequate biodiversity indicators are necessary for evaluating disturbance effects on ecological patterns and processes in an area to direct conservation management responses (Medellin *et al.*, 2000). An adequate indicator is abundant, and ecologically, taxonomically, and trophically diverse, representing a wide range of variation in terms of resource usage

within target area of management or conservation (Medellin *et al.*, 2000). Moreover, literature on chiropteran systematics, natural history, and ecology is extensive in some areas (Medellin *et al.*, 2000).

If conservation of native bats is to be effective, both large scale landscape features and small scale modifications of habitats must be taken into consideration when predicting the impacts of management practices (Warren *et al.*, 2000). Evaluation of disturbance effects on ecological patterns and processes in specific areas yields important information for conservation and management decisions. Understanding the factors that contribute to biodiversity in a region is crucial and information provides not only for understanding biology and ecology based upon scientific knowledge but also useful to land and wildlife management planning (Wang *et al*., 2003). Understanding bats' ecology provides information towards conservation of the species and for overall conservation invaluable to ecosystems of the region (Medellin *et al.*, 2000; Wang *et al.*, 2003).

1.4 Aims of the study

Despite a global current increase in interest in chiropteran faunas, little is known about Tasmanian bats and there have been only a handful of studies conducted in Tasmania over the last three decades. A species inventory is unavailable for most areas of Tasmania. Consequently, little attention has being given by authorities for conservation and management planning for Tasmanian bats. Surveys using echolocation methods would provide important information for managing bat populations. Because of the difficulty of censusing bat communities, developing a predictive model of the distribution and habitat preferences of bats using survey data would provide an indispensable conservation tool.

The primary aim of the current project is to collect distribution data to supplement previous studies, filling some information gaps about Tasmanian bats by employing acoustic survey methods to examine if there is activity period partitioning among species, and if there is species-specific differences to be determined. During summer in Tasmania when the bats are most active, spatial and temporal aspects of bat activity are most easily studied. In particular this study aims to determine distribution of bat species within the state by investigating species-specific requirements of habitat use. Short-term temporal activity patterns of species are also examined. The final object of the project is to contribute scientific data to be used for improved conservation of

Tasmanian bat species. To improve management planning in Tasmania, more information about native species is necessary to build upon the knowledge of the fauna derived from previous studies. To achieve these objectives, investigating echolocation behaviour of species to create regional reference call library is necessary.

The aims of the study therefore are:

- Create an echolocation identification key to Tasmanian bats based on reference calls obtained within the Tasmanian region
- Use acoustic methods to investigate the spatial distribution of species
- Examine and compare the nightly activity patterns of species by echolocation survey

1.5 Contents of the thesis

This thesis consists of seven chapters, and brief contents of each chapter are given below.

Chapter 1: General introduction to the world of bats and the current project objectives and aims are stated.

Chapter 2: A literature review of the biology and ecology of Tasmanian bat species based on previous studies conducted in Tasmania to date.

Chapter 3: General methods and site descriptions are given in Chapter 3. Field equipment details, assumptions and limitations of use of this equipment are also stated. Assumptions for echolocation techniques based on recommendations from other studies as well as Australasian Bat Society standards are incorporated.

Chapter 4: Chapter 4 describes the echolocation call features of Tasmanian species, as well as methods for discriminating each species call from others. Identification of calls recorded from free flying bats in later chapters were based on the automated identification programme using the key developed in this chapter.

Chapter 5: Species compositions and distributions species are analysed based upon various habitat variables such as climate; vegetation; forest type and weather conditions. Most sites sampled have never been used in previous studies, and bat inventories are provided for many sites for the first time. Habitat-species relationships determined by landscape scale gradient were sought from my data using statistical analyses.

Chapter 6: Nightly activity patterns of species are examined using metrics

such as the timing of emergence from roosts. An activity index (number of calls/time interval) is used to compare activity patterns of different bats. Statistical comparison of activity levels between species is not attempted due to differential detectability among species by the bat detectors.

Chapter 7: The general conclusion summarises the findings, and draws conservation conclusions. Management implications need to be based on scientific data collected in Tasmania. Recommendations for future scientific research on the Tasmanian bat fauna are suggested.

Chapter 2

Literature review: present knowledge about Tasmanian bats

2.1 Introduction and history

Currently, the Tasmanian bat fauna is regarded to comprise eight species representing four genera. All belong to the microchiropteran family Vespertilionidae (Table 2.1). No megabats have established colonies in Tasmania although occasional visits by vagrant individuals have been recorded on the Bass Strait islands (e.g. Taylor *et al*., 1987).
Only a small number of papers on the Tasmanian bat fauna have been published although various unpublished studies may exist, such as internal reports to government departments and unpublished theses. Much of the knowledge about Tasmanian bats is rather generalized and often extrapolated from studies undertaken on mainland populations or conspecifics.

Despite this relative neglect, Tasmania was the source of many of the original type specimens for southern Australian bats (Table 2.1). In the modern era, the first scientific studies to deal explicitly with Tasmanian populations was a series of papers by Bob Green, the zoologist at the Queen Victoria Museum at Launceston (Green, 1965; Green 1966) who clarified the identity of the species present in that state (Green & Rainbird, 1983; Green & Rainbird, 1984).

Various aspects of the ecology of Tasmanian chiropterans have been reported since the 1980's; flight patterns, foraging and feeding ecology (O'Neill & Taylor, 1986; O'Neill & Taylor, 1989); thermal energetics (Dixon & Rose, 2003); community composition (Taylor & O'Neill, 1986); nightly and annual activity patterns (Taylor & O'Neill, 1988; Taylor & Savva, 1990); and roost requirements (Taylor & Savva, 1988).
This chapter aims to summarise the known biology of Tasmanian bats based upon a review of the available literature.

Table 2.1 List of the Tasmanian bats and their type localities. Data source: http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/taxa/VESPERTILIONIDAE/complete

Scientific name	Common names	Type Locality
Falsistrellus tasmaniensis (Gould, 1858)	Eastern False Pipistrelle Eastern Falsistrelle	Van Diemen's Land
Chalinolobus gouldii (Gray, 1841)	Gould's Wattled Bat	Launceston
Chalinolobus morio (Gray, 1841)	Chocolate Wattled Bat	Tasmania
Nyctophilus geoffroyi (Leach, 1821)	Lesser Long-eared Bat	Australia
Nyctophilus sherrini (Thomas, 1915)	Tasmanian Long-eared bat	Tasmania
Vespadelus darlingtoni (Allen, 1933)	Large Forest Bat	Macpherson Range, Qld
Vespadelus regulus (Thomas, 1906)	Southern Forest Bat	King George Sound, WA
Vespadelus vulturnus (Thomas, 1914)	Little Forest Bat	Tasmania

2.2 Systematics

There has been uncertainty in the systematics of Australian bats for many years. The limits of genera have been redefined several times and the status of some populations has been upgraded from subspecies to species following recent reviews which incorporate detailed morphological comparisons and new evidence such as genetic data. For example, the endemic Tasmanian Long-eared bat. *Nyctophilus sherrini* (Thomas, 1915), was formerly considered to be a subspecies of *N. timoriensis* (Geoffroy, 1806) until recently given species status (Parnaby, 2009).

Moreover, the various *Vespadelus* species were originally referred to as a single species, *Eptesicus pumilus* (Green, 1965), along with Australia population. Revisions in late 1970's of the morphological features based upon museum specimens resolved this group into three distinct species (Kitchener 1976; McKean *et al.*, 1978). Following this, Green and Rainbird (1984) revised collections of Tasmanian specimens to conclude that all three species existed in Tasmania.

2.3 Morphology

Tasmanian bats are typically small in body size but span a five-fold range in live biomass from about 20 grams down to 4 grams (Table 2.2). All Tasmanian species show sexual dimorphism in body size and females are significantly larger than males, except for *V. darlingtoni* (Table 2.2) (Taylor *et al.*, 1987). Body dimensions in most Tasmanian bats are consistent with Bergmann's Rule, although *F. tasmaniensis* and *V. darlingtoni* are significantly smaller than their mainland populations (Taylor *et al.*, 1987).

Table 2.2 Body mass and forearm length in Tasmanian bat species and the mainland species (mean ± SD). Data from O'Neill & Taylor (1986) for Tasmanian mean, Taylor *et al*. (1987) for sex difference, and Churchill (2008) for mainland Australia. Note the mainland *C. gouldii* and *N. geoffroyi* data are sourced from Victoria/Northern Australia.

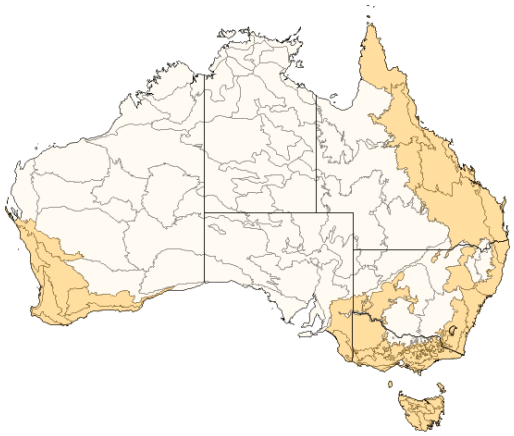
	Weight (g)				Forearm length (cm)			
Species	TAS			AUS	TAS			AUS
	♂	♀	Mean	Mean	♂	♀	Mean	Mean
F. tasmaniensis	19.4	21.3	19.8±1.9	20.5	49.4	49.9	49.5±1.1	50.7
C. gouldii	14.4	15.0	14.8±2.5	13.8/9.8	45.9	46.2	45.8±1.4	43.7/41.2
C. morio	8.9	10.0	9.4±1.2	8.9	40.2	41.2	40.6±1.1	38.9
N. geofrroyi	8.3	10.2	9.4±1.3	8.2/5.8	39.2	40.9	40.2±1.3	37.1/34.8
N. sherrini	12.7	13.1	12.8±2.0	na	45.6	46.5	46.0±1.2	na
V. darlingtoni	6.1	6.0	6.0±0.7	7.2	34.9	34.7	34.8±0.9	35.1
V. regulus	5.0	5.5	5.4±0.7	5.2	31.4	33.2	32.9±0.9	31.2
V. vulturnus	4.1	4.5	4.2±0.4	3.9	29.1	29.7	29.3±0.7	28.4

Wing morphology plays a particularly important role in chiropteran ecology. Wing load and aspect ratio determine flight speed and manoeuvrability, and hence the flight patterns of the species. Aerodynamic theory predicts decreased manoeuvrability with increased body mass (Farney & Fleharty, 1969; Aldridge & Rautenbach, 1987; Norberg & Rayner, 1987) and Tasmanian bats are no exception (O'Neill & Taylor, 1986; Rhodes, 1996). Rhodes (1996) suggested wing morphology is a key limiting factor of species distribution, rather than local availability of food resources in Tasmania

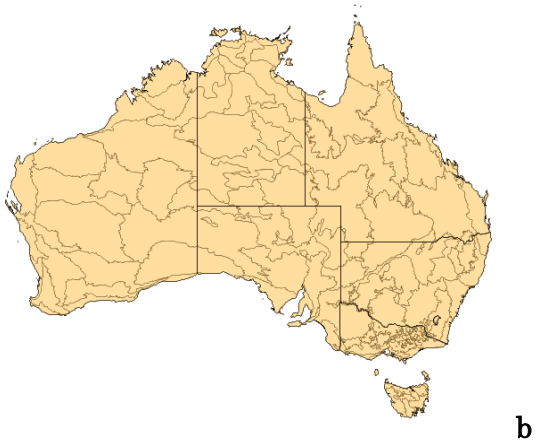
as total biomass of the insect pool may not change greatly in space and time.

2.4 General distribution and relative abundance

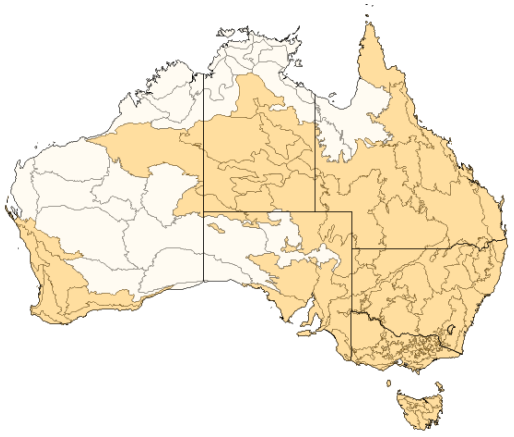
Tasmanian bats species, except the endemic *N. sherrini*, occur widely over the Australian mainland, and are mainly distributed from the north east coast down to south-eastern coast regions (Fig. 2.1). The distributions of any species within Tasmania have not been clarified in detail, but in general, most are believed to be widely spread (Duncan, 1995). Only a few distribution surveys on bats within Tasmania have been conducted, and fewer have been published. Some appeared to occupy only three to five percents of the state's land (Rounsevell *et al.*, 1991). Considering the agility, locomotion and distribution range of mainland populations, it is most likely that this is an under-estimation of their true range, suggesting that much more distributional survey remains to be done. Distributions of the various Tasmanian species, from limited resources, appear largely overlapping and a number of species can be sympatric in many habitats. This seems particularly true in eastern Tasmania as a number of studies confirmed multiple species captured at a single site (e.g. O'Neill, 1984; Taylor *et al.*, 1987).



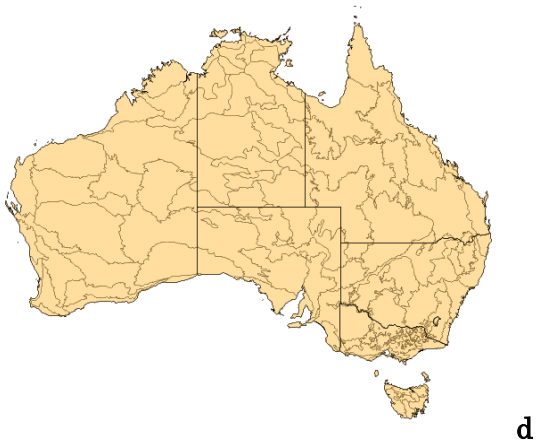
Falsistrellus tasmaniensis



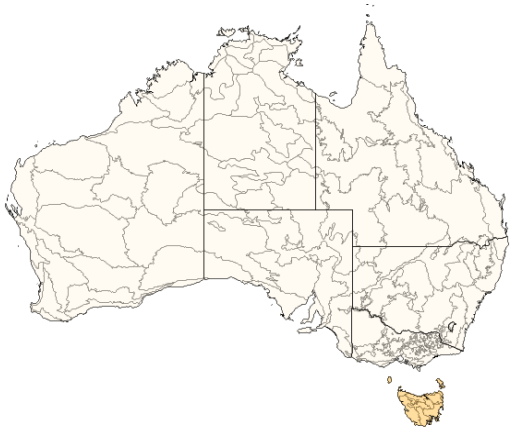
Chalinolobus gouldii



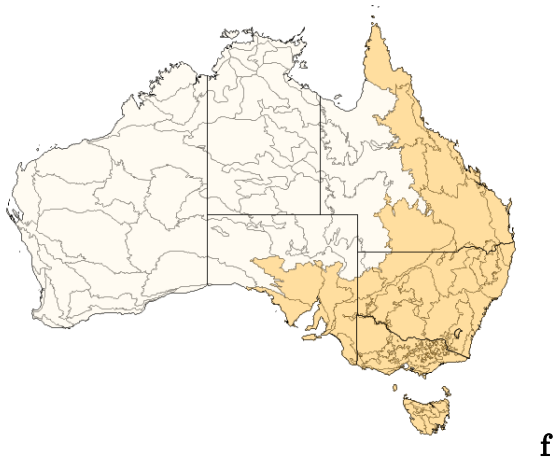
Chalinolobus morio



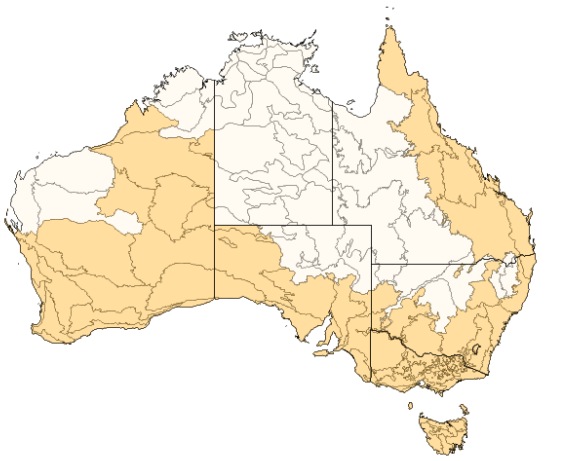
Nyctophilus geoffroyi



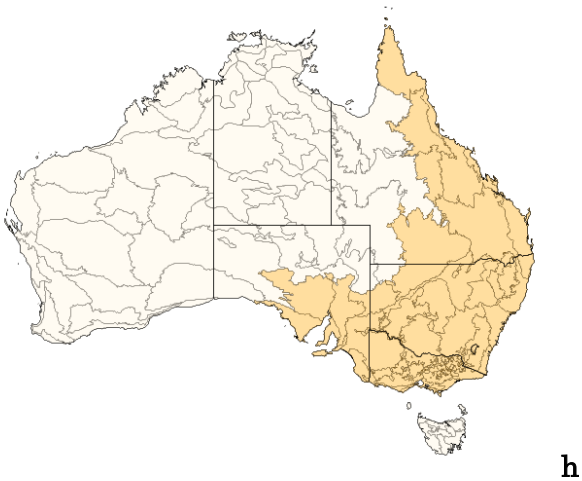
Nyctophilus sherrini



Vespadelus darlingtoni



Vespadelus regulus



Vespadelus vulturnus

Map source:

http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/taxa/VESPERTILIONIDAE/complete

Figure 2.1 Tasmanian bats species and their conspecific mainland distribution in Australia. Distribution records were extracted from IBRA and IMCRA. (Note: *V. vulturnus* inhabits Tasmania, but is not indicated on Map h).

Differences in the relative abundances of each species are not clearly demonstrated. However, previous studies suggest that the larger species, *F. tasmaniensis*, *C. gouldii* and *N. sherrini* are less abundant than the other species (e.g. O'Neill, 1984; Taylor *et al.*, 1987). Species richness seems to be lower in southwest and western Tasmania. Seven to eight species commonly occur at one site in the majority of the eastern parts of the state (O'Neill & Taylor, 1986; Taylor *et al.*, 1987), whereas less than 4 species were captured at a site in the western region (Schulz & Kristensen, 1993). The occurrence of *V. vulturnus*, *V. regulus* and three larger species, *N. sherrini*, *F. tasmaniensis* and *C. gouldii* may be limited within the perhumid cold climatic zone (i.e. State's southwest including the South West National Park) (Rounsevell *et al.*, 1991; Schulz & Kristensen, 1993). However, Schulz and Kristensen (1993) recorded seven of eight species along a coast line of SWNP, except *F. tasmaniensis*. The most frequently captured species in SWNP was *N. geoffroyi* and it appears to be the only widespread species in this area and some other parts of Tasmania (Rounsevell *et al.*, 1991; Driessen & Mallick, 2003). This eastern/western difference is assumed to be the resulting of a combination of higher rainfall and colder climate conditions, and less insect abundance in western Tasmania (Taylor *et al.*, 1987; Taylor & Comfort, 1993; Schulz & Kristensen,

1993). Moreover, parts of western Tasmanian support tall, dense temperate rainforests which may restrict faster, less manoeuvrable species from utilising this niche (Rhodes, 1996).

Some species make use of human environments in addition to natural habitats. *F. tasmaniensis* and *N. geoffroyi* are often observed roosting and foraging in urban and inner-city situations (Taylor *et al.*, 1987). This preference may explain partly why *F. tasmaniensis* is the least common species in temperate rainforests or mature forests due to their fast and less manoeuvrable flight (Rhodes, 1996), suggesting urbanization may provide this species with additional habitat opportunities. *Vespadelus* species are also known to form maternity colonies in attics and buildings (Green, 1965), although there are no reports of *Vespadelus* species utilising urbanised areas as a feeding habitats in the same way that *F. tasmaniensis* and *N. geoffroyi* exploit this environment.

2.5 Habitat and roost ecology

Tasmanian bats are forest dwellers, which primarily roost in tree elements such as hollows and barks (e.g. Taylor *et al.*, 1987). Tasmanian bats, like most temperate bats, are generalists in terms of habitat requirements (Taylor, pers. comm.). However, their roost preferences appear to be towards older, larger trees that provide higher insulation and safer diurnal refuge (Taylor *et al.*, 1987). There have been anecdotes of the presence of a small number of bats in local caves (Arthur Clark, pers. comm.), but there are no reports confirming permanent establishment of cave roosts in Tasmania (Taylor & Savva, 1988).

Tasmanian bats usually live solitarily or a small number of individuals share roosts in trees and other structures. Even though aggregation occurs at some stage of the reproductive cycle, the formation of maternity colonies is common during spring and summer (e.g. Green & Rainbird, 1984). *Vespadelus* species appear to be communal throughout the year, and their maternity colonies tend to comprise a bigger cluster than other species. *V. regulus* females form large colonies of up to 50 individuals. The largest maternity colony consisting of 60 individuals of *V. vulturnus* was reported in northern Tasmania (Green & Rainbird, 1984). *V. regulus* roosts sexually separated except in mating seasons, even though females congregate in large numbers, males gather in typically small groups of up to five individuals.

Habitat preferences seem to exist in Tasmanian bats in some extent, but are not often consistent across different environments. *C. morio* tends to live along

watercourses with large trees where they roost in tree hollows and under exfoliating bark. *N. geoffroyi* is adaptable to a variety of conditions, although appears less abundant in dry sclerophyll and regrowth forest (Taylor *et al.*, 1987). *N. sherrini* tends to inhabit humid areas such as blackwood swamps, coastal mallee and wet sclerophyll forest (Taylor & O'Neill, 1986). *V. regulus* is present in almost all habitat types, but may prefer the highlands and wet sclerophyll forests (Green & Rainbird, 1984; Taylor & O'Neill, 1986; Rhodes, 1996). *V. vulturnus* prefers low altitude inland areas dominated by dry sclerophyll forest (Green & Rainbird, 1984; Taylor *et al.*, 1987). This is consistent with mainland populations which are uncommon above 1000m altitude (Young & Ford, 1998; Churchill, 2008).

2.6 Diet and foraging

The diet of Tasmanian bats is influenced by the strong seasonality of their environment and they should be opportunistic feeders particularly in the winter period when flying insects are scarce. Opportunistic feeding by temperate bats has evolved in response to the seasonal availability of limited resources. Partitioning of food resources also appears to exist by vertical axis (i.e. flight heights) among the Tasmanian bat community (O'Neill & Taylor, 1986; Taylor & O'Neill, 1986). Nevertheless, on admittedly limited evidence, some of them appear to show specialized diet types.

For Tasmanian bats, Lepidoptera appears to be the most important food source, followed by Coleoptera (O'Neill & Taylor, 1989) and the trend seems consistent across most of Tasmania, although slight variation in diet composition occurs between regions, which appears to be caused by variation in insect availability (O'Neill & Taylor, 1989). *Vespadelus* species, *N. geoffroyi* and *C. morio* are more opportunistic than other bats, consuming a wider variety of insect orders (O'Neill & Taylor, 1989). *F. tasmaniensis* and *C. gouldii* are more selective on Coleoptera (Taylor *et al.*, 1987; O'Neill & Taylor, 1989). *Nyctophilus* species have the capacity of gleaning to feed on non-volant prey such as caterpillars, yet only *N. sherrini* appears to be specialised on non-volant insects (Taylor *et al.*, 1987; O'Neill & Taylor, 1989).

For some species their diet is strongly influenced by the regional availability of insects. For instance, in *V. regulus* only 6% of the diet is composed of flies in Tasmanian populations, whereas flies are the primary dietary component (47%) in Victoria (O'Neill & Taylor, 1989; Churchill, 2008). Tasmanian *C. morio* preys on moths (56%) and beetles (20%) which suggest that the Tasmanian population is more generalist than

Victorian populations which predominantly target moths (94%) as prey. Interestingly *V. darlingtoni* shows an opposite trend in that Tasmanian populations predominantly consume moths (60%), whereas in Victoria the species evenly takes from a wide variety of insect orders; ants (26%), flies (25%), bugs (20%), and beetles (19%) (O'Neill & Taylor, 1989; Churchill, 2008).

2.7 Hibernation

Of the diverse families of bat fauna, only a small number have successfully colonised the higher latitudes of the northern/southern hemispheres. High latitude species are limited to two families; the Rhinolophidae, and the Vespertilionidae (Arlettaz *et al.*, 2000). To be successful in high latitudes bats must adapt to extreme conditions associated with seasonally low temperature. Migration and hibernation are the most common strategies for overcoming the harsh conditions during winter. Long distance migration appears less favoured among the temperate bat community, even though the number of species which hibernate is relatively small. Approximately 10 percent of species are capable of hibernation (Findley, 1993).

Hibernation is one of the most notable aspects of the temperate bat biology and contributes a major part of the life cycle. Hibernation, often described as "prolonged torpor", is however fundamentally different mechanism from torpor. Torpor is widely employed by most of bat species from tropical to temperate regions. Torpid bats decrease body temperature to minimise energy loss during sleep which is maintained within a 1℃ difference of ambient temperature and they do not need an external heat source to arouse at all. During hibernation bats keep a body temperature differential with the environment of less than two degrees Celsius (Arlettaz *et al.*, 2000), yet do not drop below freezing point. To counter an excessive drop in the ambient temperature below zero, bats need to increase their body temperature to maintain minimum functions for survival (Neuweiler, 2000; Funakoshi *et al.*, 2007).

All Tasmanian bats are capable of hibernation. *N. geoffroyi* in Tasmania becomes torpid at much lower ambient temperatures (15℃) than that of mainland populations (25℃), and the basal metabolic rates for Tasmanian population are considerably lower (Dixon & Rose, 2003). *C. morio* have the shortest hibernation period as this species starts hibernating later and emerges earlier than the others, which is consistent in both Tasmanian and mainland populations (Taylor *et al.*, 1987; Taylor & Savva, 1990; Churchill, 2008). Turbill (2006) found that male *C. morio* is active at the

beginning of the hibernation period, having repeated arousals of much shorter period than females. Hibernation in *C. gouldii* only takes place in the cooler part of the range including the Tasmanian region (Churchill, 2008).

Tasmanian bats are well adapted to a high latitude climate and some species can maintain body weight almost unchanged through hibernation (Taylor & Savva, 1990). Presumably, bats arouse frequently and have some success in sourcing energy during the hibernation period. In colder months, bats can fly at an ambient temperature of as low as 2℃ (Inada, 2006).

2.8 Reproduction

Reproductive activities of bats are closely approximate between mainland and Tasmania (Green & Rainbird, 1984; Taylor *et al.*, 1987), yet the timing and duration of each reproductive phase varies with the influence of climatic factors such as latitude and elevation, which most likely determine the timing of hibernation (Taylor *et al.*, 1987). Maternity colonies start forming sometime between September and October; gestation periods are generally about three months, but can last four to five months in *C. morio* (Churchill, 2008). Parturition takes places in late November to mid December. Tasmanian bats appear to be monestrous, giving birth to one to two young per year. *N.geoffroyi, N. sherrini* and *C. gouldii* are known to bear twins each year while other species normally give birth to one young (Green, 1966; Green & Rainbird, 1984; Taylor *et al.*, 1987). The birth is occurred during day-light hours in captive *N.geoffroyi* (Green, 1966).

Lactation finishes by early February and *C. morio* finishes lactation later than other species (O'Neill, 1984; Taylor *et al.*, 1987). Young start flying independently at about six weeks old, and *V. vulturnus* young do not start flight till 50 days old (Green & Rainbird, 1984).

Males and females differ in the time need to reach reproductive maturity. Females become sexually mature in the first year and males in the second year after the first hibernation (Green & Rainbird, 1984). Timing of copulation differs between species. In most species mating occurs in autumn, yet *C. morio* and *V. darlingtoni* are sexually active throughout the hibernal period (Turbill, 2006; Churchill, 2008).

Hibernation is a strategy to survive through the harshest months of year in the temperate zone, and because of this limitation bats cannot reproduce continuously unlike some other small mammals. Temperate bats have overcome this problem by

employing unique mechanisms; prolonged sperm storage in the epididymis in the male, delayed ovulation and delayed implantation in the female (Neuweiler, 2000; Churchill, 2008).

2.9 Conservation status

All Tasmanian chiropterans are currently fully protected in Tasmania, under various state legislations. These are *Nature Conservation Act 2002* and *National Parks and Reserve Management Act 2002* (formerly National Parks and Wildlife Act 1970), *Wildlife Regulations 1999* (regulation no. 3 (1), Schedule 2 as protected wildlife. Despite their legal status, very little active conservation activity so far has been implemented to conserve of these species. All eight species feature on the IUCN Red List of Threatened Species. Seven species (*C. gouldii, C. morio, F. tasmaniensis, N. geoffroyi, V. darlingtoni, V. regulus, V. vulturnus*) are listed Least Concern (ver. 2.3 1994; ver. 3, 2009), and *N. timoriensis* (now known as *N. sherrini*) is categorised Vulnerable criteria A2c (ver. 2.3 1994). *N. sherrini* was reviewed and separated from *N. timoriensis* in 2008, and the status is given the species data deficient in ver. 3. (IUCN, 2009). The conservation status of species in IUCN revision included mainland population as well, and no actual status of Tasmanian population is clear.

Chapter 3

General methods and site description

3.1 Introduction

Throughout the course of the project, bat activity data was collected by acoustic recording of free flying bats supplemented by field capture where necessary. Some field sites were repeatedly observed to collect activity data especially in the vicinity of greater Hobart.

In this chapter, the range of methods used is described and justified. The details of sites sampled are given as well as equipment details.

3.2 Permits and ethics approvals

The study was conducted under the University of Tasmania Animal Ethics Committee approval No.A00976, Department of Primary Industry and Environment scientific permit No.FA08630, and Hobart City Council Land Use permit No.4/2009.

Handling wild animals has the possibility of transmitting pathogens. Risks in Australia include rabies and Australian Lyssavirus. Risks associated with both human and animal health were carefully considered (e.g. repeated vaccination against rabies) and precautions were taken seriously while handling wild animal (see appendix ii for health issues).

3.3 Study sites

All sites data collected are summarised in Fig. 3.1; site coordinates are listed in appendix i. Sites were chosen to represent a range of environments considering the following range of attribute - accessibility; accommodation availability (i.e. campsite nearby); degree of disturbances such as usage, proximity to night activity, and

remoteness. In addition to carrying large amount of equipment, because of the nature of night survey, it was not preferable to set a site too close to human activities or too remote, particularly on weekends and in the holiday season. Any risk involved in the night survey (e.g. assault, vandalism, theft, shooting and others) was considered and mitigated with appropriate precautions as documented by bat survey manuals (Joint Nature Conservation Committee, 2004; Bat Conservation Trust, 2007).

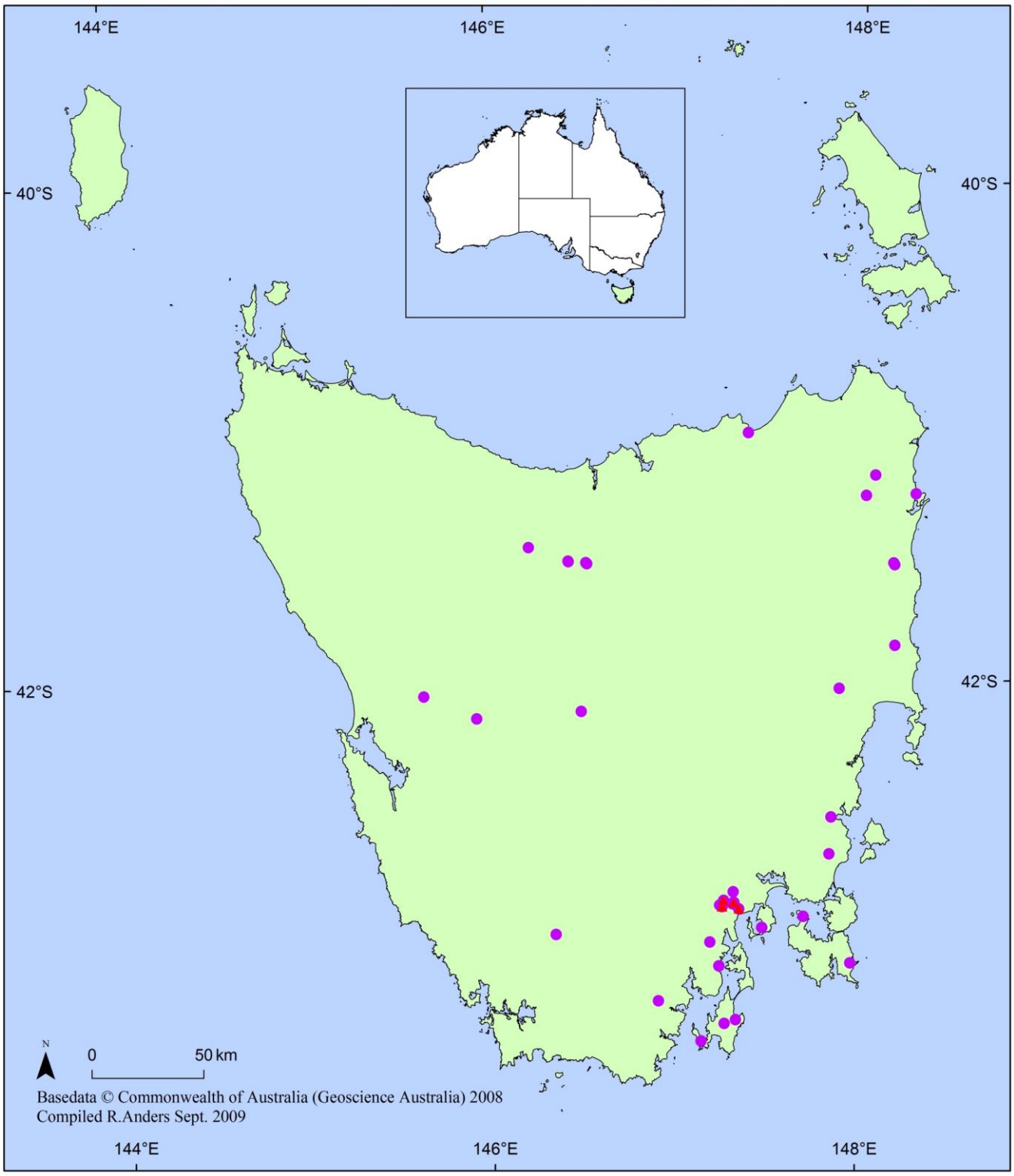


Figure 3.1 Site map. Acoustic survey sites are indicated as a purple closed circle and trapping sites are indicated by a red triangle.

3.4 Data sampling methods

Fieldwork was conducted over two summer seasons; September 2007 to April 2008, and October 2008 to March 2009. Additional fieldwork was conducted opportunistically in other months when possible, so that at least some data was available for most months of the year. Supplemental call data were obtained from several sources (e.g. Inada, 2006).

Weather conditions were variable and can affect results. Bat activity is known to be depressed by heavy rain (Taylor *et al.*, 1987) and these conditions can make field equipment less effective. Therefore, fieldwork was avoided on rainy nights. The effect of strong winds upon the activity of bats is poorly known, but recording devices are less successful as winds cause ultrasound nuisances which reduce the recording quality of echolocation calls. High winds also risk the harp-trap being knocked over and tree branches falling from above. Therefore those conditions were also avoided.

Nightly fieldwork started just before sunset and finished after sunrise. Data sampling were strictly confined between sunset and sunrise. Sunrise/sunset time was calculated using Anasun software (Corben, 2006) based upon geographical coordinates at 42°54’11”S, 147°19’40”E (i.e. University of Tasmania, Sandy Bay campus) and it was applied to all sampling sites regardless of actual differences of latitude, longitude and altitude. Other studies defined “night” with visually confirmation of “total darkness”. However, the timing of nightfall is strongly influenced by location and surrounding situation including tree density, aspect of places and etc and visual confirmation without standardised aid may bias the length of night and hence activity pattern analyses. Therefore sunset/sunrise timing was mathematically calculated based on fixed coordinates.

3.4.1 Harp-trapping

Harp-traps and mist-nets are most commonly used for capturing free-flying bats. For the current project, harp-traps were used to collect live specimens because of their convenience and proven efficacy in trapping live animals.

Harp-traps are specifically designed to capture free-flying bats. The trap typically has a pair of banks comprising vertical strands of monofilament fishing line (Fig. 3.2). It is thought that bats flying in the vicinity of these traps are not be able to efficiently detect the very thin lines because they difficult for the echolocation sound to reflect from. When they fly into a trap, the first harp allows them to proceed but the second harp stops the bats from proceeding as it disturbs its wingbeats. Once bats are

confined between the two harps without effective wingbeats they are forced to slide down into a catching bag attached below the trap. The bag design incurs no physical damage to the animal and bats normally stay calm to conserve energy.

In the course of the study, monofilament fishing line of approximately 6lb (~3kg) with a thickness of 0.2mm was used. This diameter line was selected to fulfil recommendations on harp-trapping Australian microchiropterans (Gration, 2003).

The frame size is approximately 153cm in width and 161 cm in length, but the harp size slightly changes due to line condition, environmental situations, and condition of storage between uses. The tension in the lines causes some distortion which is greatest in the middle (~5cm). Line tension, and thus the size of harp net, may vary according to environmental conditions. Monofilament nylon line will absorb 4-8% of water per volume and it can stretch up to 50% of its length under extreme humidity and heat (Gration, 2003). Highly changeable weather made the monofilament lines vary in their tension. The lines needed to be checked at each set-up and whole sets had to be replaced 4 to 5 times over the two year course of the study. There is no standardized measure of optimal line tension for trapping target species, although it is suggested tension should be set based on the flight speed of subjects as if the lines are too tight bats will bounce off when they hit the lines. On the other hand, the lines will produce nuisance sounds due to wind if they are too loose. In this project the lines were kept as tight as possible at first lining and loosen lines were replaced whenever possible.

The lines are tied at intervals of 2-3cm (average of 63 lines per side), which is slightly wider than the head size of Tasmanian bats (*V. darlingtoni* = 1.2cm to *F. tasmaniensis* = 1.8cm) (Green & Rainbird, 1983Churchill, 1998). This was considered appropriate intervals by which to sample all Tasmanian bats species.

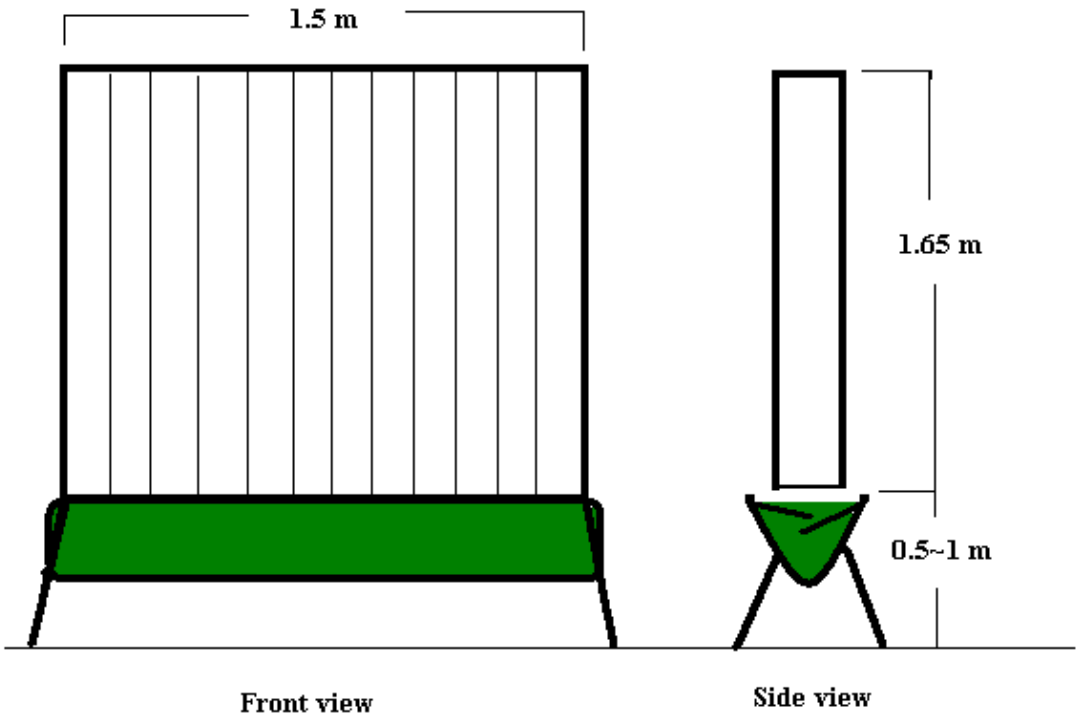


Figure 3.2 Basic design and size of a harp-trap used in the study

Catching bags of the traps were also modified. The flaps on the top of bags that prevent trapped bats from escaping need to be carefully adjusted (Bradley Law, pers. comm.). Aforementioned, Tasmanian bats are relatively small (approx. 4~20g). When the flaps are not properly angled intercepted bats may land on them and easily fly off. Other problems are that they can crawl out of gaps the size of their head and can also use their strong jaws to rip soft materials such as plastics and the canvas bag. This problem was solved by covering holes and gaps by high quality duct-tape and placing baffle sheets in between the two flaps (Fig. 3.3 a & b).

a) b)

Figure 3.3 Modified catch bag designs of harp-traps used for the project

The harp-trap has a small fixed catching area and catch success is strongly influenced upon setting up in the right place. The traps are most effective at restricted flyways in forest, preferably covered by overhanging vegetation that channels bats' flight direction towards the trap. Set-up locations thus had to be chosen accordingly to the property and size of harp-traps used in the study. The best result can be obtained by setting up traps at acute corners on the flyway, which make traps less detectable to bats. Harp-traps are normally set up solo but when the flyway exceeds a single trap width two traps were set side by side (Fig. 3.4). Trapping locations were selected based on prior knowledge of bat presence by acoustic survey (Inada, 2006), accessibility, and trapping suitability including vegetation covers, recreation usage, disturbance, and flyway conditions. No site was used for subsequent nights. Taylor & O'Neill (1986) reported that catchability decreases dramatically after the second night at a site.

Each trap was checked every 30 minutes to an hour for bats' presence from set-up time to around midnight, and then checked again at least one hour before sunset next morning. On a number of nights, trapping were unsuccessful, but the largest catch of 16 individuals in a trap occurred on a night in February, 2009.

Bats captured by the last checking in the night were examined at each checking, and after midnight captures were done next morning before sunrise. It was found that the best timing of release and recording of each individual is just after sunrise, because trapped bats normally went to torpor in the traps and they appeared to save sufficient energy to fly back to roost without obvious difficulty. In dim light, the bat flying away could still be visible and hence artificial marking was not necessary, as well this time of release lowers predation risks from night predators such as owls.

Figure 3.4 Single harp-trap set up on flyway on the Pipeline Track, Mt. Wellington

Individuals caught were examined to allow identification and measurements were taken at the site (Fig. 3.5). Species identification was made primarily based on several identification keys provided by Taylor *et al.* (1987); Hall and Richards (1979); and Parnaby (1992), additionally Churchill (1998, 2008) when necessary. Along with identification, measurements included forearm length (callipers), body weight (50g spring balance). Other data (e.g. sex, age category (juvenile, sub-adult, adult), and reproductive stage) were collected when possible. The external condition of each bat was also checked for the presence of injuries/wounds which could be incurred by trapping. Partly due to the small number of successful captures, no animals appeared to have obvious injury or wound, or were adversely affected by handling during examination.

a) b)

c) d)

Figure 3.5 Capture of bats for reference calls, from 2 least common species and 2 most common species; a) Eastern falsistrelle, *F.tasmaniensis*; b) Tasmanian Long-eared bat, *N. sherrini*; c) Large forest bat, *V. darlingtoni*; d) Little forest bat, *V. vulturnus*.

3.4.2 Acoustic sampling

The use of the Anabat system and accessory programmes used for analyses of echolocation calls in the course of the study are described in chapter 4 and other use of the programme features should be referred to the Anabat operation manual (Corben & O'Farrell, 1991). In this chapter, therefore, a brief outline of the system is given.

Anabat II bat detectors and Compact Flash Card Zero Crossing Analysis Inter Modules, CFC-ZCAIMs, (Titley Scientific, Ballina, NSW) were used for acoustic recording of bats' echolocation calls. It employs frequency division system to transform

echolocation calls into audible signals and zero-crossing analysis to view the spectral content (Milne *et al*., 2004). A number of authors argue advantages/disadvantages of different mechanical applications of the ultrasound recordings (e.g. Parsons *et al.*, 2000; Fenton *et al.*, 2001; Patriquin *et al.*, 2003; Milne *et al*., 2004). In Australia, Anabat is the most widely distributed and used among authorities and researchers. The Australasian Bat Society resolved to recommend minimum standards for acoustical surveys on bat fauna and reporting related assessments. The standardisation of survey and report methods was derived because of rapidly growing use of bat detectors since early 1990s and as a result problems associated with inadequate methodology and insufficient amount of survey efforts used in management and conservation planning, along with transparency in the identification of bats calls are particular concern (Reardon, 2003; Pennay *et al*., 2004). The main aim of the standardisation is to overcome problems associated with call analysis caused by either underestimation of variation with bat calls or overlapping call characteristics amongst species, meanwhile increasing comparability and repeatability of studies as well as increasing reliability of interpretations of those studies.

The bat detector survey report standard by the Australasian Bat Society (2003) is shown below:

- description of the reference library
- details of the number of detector hours undertaken
- "time vs. frequency" graphs of each spp used for identification
- description of the characteristics used to distinguish similar calls must be in the method
- indication of the proportion of call identified, percentage of identified/ all processed calls
- collection/deposition of all the call file

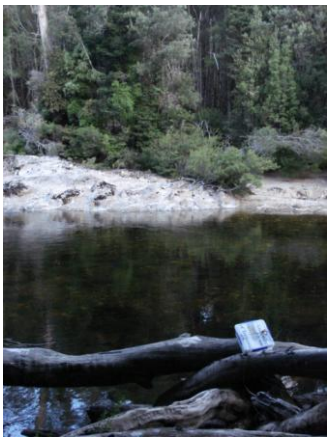
The current project recognised the importance of the ABS standards on acoustic survey on bats and was intended to follow them as much as possible. Chapter 4 deals with the standards with emphasis upon these points.

Various constraints are associated with acoustic surveys of bats and inherent limitation and assumptions should be articulated. Assumptions related to data collection and analyses in the current study is summarised below which were derived and modified from Sherwin *et al.* (2000) and Hayes (2000);

a) Detectors reliably and consistently detect echolocation calls emitted by bats
b) Amount of calls recorded at a site reflects amount of use by bats
c) Data collected at a site reflects use of other sites having similar characteristics
d) Amount of activity recorded at a site reflects quality of habitat
e) Bats can be reliably identified to taxon
f) Captures are correlated with the habitat type in which call sequences were detected
g) A capture is treated as independent event
h) Captures were defined as a sequence of search phase call with at least 5 pulses
i) All bats are assumed to be distributed randomly in a vertical space
j) Bat detectors are assumed to have the same detectability, and all species are treated as emitting equally detectable echolocation call
k) Spatial variability is solved by recording at the similar habitat
l) Temporal variability is addressed in analysis
m) Conclusions represent local events, yet data collected at a site reflects patterns of use of other area having similar characteristics.

3.4.3 Environmental data

Weather conditions including ambient temperature, relative humidity, Average wind speed, cloud cover, precipitation, and elevation were recorded at site. Habitat variables include forest types, dominant vegetation, distance to water nearest were retrieved from the Land Information System Tasmania, the List map (www.thelist.tas.gov.au) and TASVEG 2.0 (Tasmanian Vegetation Monitoring and Mapping Program). Habitat variables were featured area of 1000m grid which centred a recording site. Categorisation of forest groups and vegetation types were described in later chapters. Few examples of sites from different recording conditions are shown in Fig. 3.6 below.



a)

b)

c)

d)

e)

f)

Figure 3.6 Examples of Anabat acoustic recording sites in Tasmania : a) Anabat near riparian rainforest, Collingwood River; b) A roost tree in a residential area, Sandford; c) On the edge of forestry coupe in dry sclerophyll forest, Gould's Country; d) Sandy bush track and low vegetation cover in open woodland, South Bruny National Park; e) Temperate rainforest with Antarctic tree ferns, Sandpit; f) Narrow walking track in dry sclerophyll forest, surrounded by dense understorey, Truganini Reserve

Chapter 4

Species identification by echolocation calls

4.1 Introduction

Echolocation is an active process of perceiving the surrounding environment by emitting and receiving sound and its echo. Once a pulse emitted it will travel to an object and bounce back to the bat's ear.

The capacity for bio-sonar has been independently evolved in relatively few mammals (i.e. bats, cetaceans and some nocturnal rodents) and birds (i.e. cave swiftlets and oilbirds). Most of these animals use bio-sonar as a means of orientation and its system is far less complex than the one used by bats. Echolocation used by bats enables for orientation, detection and localization of prey, and could be used for a mean of communication (Speakman & Racey, 1991; Funakoshi *et al.*, 2007).

Chiropteran echolocation calls are characterised by a sequence of short, periodical, high frequency pulses, which normally exceed the human audible range (i.e. above 20 kHz) (Jones, 2005). Dominant frequencies of the sound used in bats' echolocation calls are within a range of frequencies approximately 11 kHz to as high as 212 kHz (Fenton & Bell, 1981). Types of echolocation call are conventionally categorized into two groups: constant frequency calls (CF calls) and frequency modulated calls (FM calls). Most echolocating bats use combinations of CF/FM call components over a particular frequency range and consequently many of these echolocation call patterns are distinctive and species-specific. The properties of echolocation calls are under the influences of the bat's physiology, flight morphology and feeding ecology. When diagnostic features of the echolocation call are known for a particular bat species, call records can be used as a reliable identification tool (Macias *et al.*, 2006).

Identification of free-flying bats in natural environments by echolocation calls has been widely employed in Australia and other countries in recent years. The use of acoustic detection has been demonstrated to be a powerful supplement to contemplate standard capture methods to identify insectivorous bats that are generally under

represented in field inventories (e.g. high flight bats) (Macias *et al.*, 2006).

There is considerable variability in echolocation call features, reflecting differences in behaviour, species, and situation (Fenton *et al.*, 2001). The echolocation structures of a bat species can vary between sex (Jones *et al*., 1992; Kazial & Masters, 2004), age (Jones *et al.*, 1992), individual (Gelfand & McCracken, 1986; Obrist, 1995), and presence of other individuals (Obrist, 1995). However, the flexibility and adaptability of bat echolocation calls is limited and is, to a considerable degree, species-specific (Herr *et al.*, 1997). This is because the fine-scale morphology of the sound-making apparatus is generally species specific. This does not mean that all bat calls are identifiable, but rather that each taxonomic group is more likely to share a set of echolocation call characteristics (Herr *et al.*, 1997). Echolocation calls of some bats in Australia have been extensively studied, and in comparison of conspecific populations, Tasmanian species are apparently distinguishable by their search calls, with exception of two species of *Nyctophilus geoffroyi* and *N. sherrini*.

The Anabat system transforms a call into a digital data file of the frequency-time domain, a spectrogram, not the frequency-amplitude domain, a power spectrum. Patterns of amplitude inputs are lost during transformation so that those calls with similar sound frequency but different amplitude pattern cannot be distinguished.

The variation in calls can be considerable between genus, species and populations. For example, *Vespadelus pumilus* and *V. troughtoni* in New South Wales and Queensland have little or no variation, whereas *V. regulus* and *V. vulturnus* have considerable differences in their calls (Law, 2003). *Falsistrellus tasmaniensis* (Pennay *et al*., 2004) and *Chalinolobus gouldii* (Reinhold *et al*., 2001) in mainland Australia have been demonstrated to have no significant regional differences within species. In other species, intra-specific variation in echolocation call types can occur between geographically separated populations. Therefore keys for echolocation call identification must take into account the extent of geographic variation (e.g. Reinhold *et al*., 2001; Law, 2003; Reardon, 2003; Pennay *et al*., 2005).

A regional library is a collection of quality calls (i.e. with relatively low signal to noise ratio) from local individuals identified using methods other than echolocation features. Reference calls should represent a full spectrum of call variations within species from a defined biogeographical region (de Oliveira, 1998; Law, 2003). The limits of biogeographical regions for the Tasmanian bat fauna are unclear and thus in my study it was decided to treat the whole state as one region.

Recently developed hard/software in support of acoustic survey allows the collection of very large amounts of sample data in a relatively short period of time.

However, the manual handling of such large amounts of raw data sets requires increasingly more time.

Traditional qualitative methods, or visual identification, of echolocation calls collected by bat detectors are still commonly used and are effective especially for monitoring free-flying bats at the site. These methods are based on visual comparisons of recorded calls against identified call catalogues (O'Farrell *et al.*, 1999). However, when large amounts of data need to be analysed, manual confirmation is time-consuming and can be arbitrary in that results are not readily repeatable by other persons.

More recently, a number of quantitative methods for call identification have been developed using mathematical algorithms, which provide results that are objective, repeatable and consistent regardless of observer experience (Jennings *et al.*, 2008). The error rate associated with the analysis, and any bias introduced by the analysis, should be uniform (Jennings *et al.*, 2008). Quantitative methods are based on categorisation of calls by predefined criteria on call features including multivariate statistics and learning. Discriminant function analysis (DFA) (e.g. Woodside & Taylor, 1985; Jolly, 1997; Parsons & Jones, 2000; Wilson, 2003) and decision tree classification systems (e.g. Herr *et al.*, 1997) are the most frequently employed methods. Other researchers have attempted more complex systems to obtain a higher level of accuracy. These include artificial neural networks (ANN) (Jennings *et al.*, 2008; Parsons & Jones, 2000) and support vector machines (SVM) (Redgwell *et al*., 2009).

Other advantages of quantitative analyses are that improvement of identification is possible by training the algorithms when new reference calls become available and can classify unidentified calls into predefined species or species complexes. Disadvantages include the fact that the quality/reliability of identification is highly dependent on the quality of the classifier (Jennings *et al.*, 2008) and certain calls are indistinguishable such as alternated signals (e.g. *C. gouldii*) which are obvious species-specific features to human eyes.

In Tasmania there are neither reference calls nor a regional library available. The aims of this chapter are to create a reference library for an assemblage of Tasmanian bats and to test the use of this reference key for identifying free-flying bats using data collected in the course of the study.

4.2 Methods

4.2.1 Obtaining reference calls

Reference calls were obtained from captured live specimens (see Chapter 3 for trapping methods used). One or two sets of harp-traps were deployed each night of trapping. Harp-trapping was conducted over 19 nights for a total of 120 trapping hours.

In total, 27 individuals from 6 species (*F. tasmaniensis*; *N. geoffroyi*; *N. sherrini*; *V. darlingtoni*; *V. regulus*; *V. vulturnus*) were captured. Once positive identification was made, each individual was released for recording. To obtain better quality calls from released bats, several criteria were taken into account for choosing release locations. An open area surrounded by thick and taller vegetation ensured that the flight path of released individual would be more or less predictable and allowed recording over a longer period. Transportation time was minimised before release to reduce distress to bats. Additionally the familiarity to the release environment may also minimise a ratio of distress calls search phase call within a set of recording.

Each bat was released from an observer's hand, while a bat detector was turned on. An observer moved the detector to follow the bat until it was out of sight or the detector stopped responding. Two sets of bat detectors were used to maximise the chance of obtaining better quality calls when possible, because recorded call quality is situation-dependent.

Obtained reference calls were treated the same way as other call data on the basis of assumptions annotated in chapter 3. A call is defined as a series of repetitive pulses that continues for at least five pulses. The Anabat system cannot record for longer than 15 seconds at a time and any call sequences lasting longer than 15 seconds were saved onto two separate files, and hence treated as two calls. Moreover, bat detectors do not usually constantly record a whole sequence of calls from a hand-released individual from the moment of release until it flies away because of the distance to the bat, call strength, flight behaviour and other nuisance factors. Therefore a few calls or call files can be recorded from the same individual.

In total, 63 hand-released calls were obtained from captured bats, supplemented with 57 calls, which were collected by other researchers in Tasmania (B. M. Law, unpubl. data; L. Cawthen, unpubl. data). All recorded calls were analysed both qualitatively and quantitatively to enhance the accuracy of identification.

4.2.2 Identification key for echolocation calls

The steps to create the identification key are described below. As the result of the lack of any *C. gouldii* reference calls, the species was excluded. Even though no statistical comparison was conducted on *N. geoffroyi* and *N. sherrini*, indistinguishable calls among species of genus *Nyctophilus* are well documented (Duncan, 1995; Rhodes, 1996; Pennay *et al.*, 2004), and hence calls from these species were lumped together to represent *Nyctophilus* spp. Finally, the identification key was intended to classify calls into six taxa.

Step 1: All call sequences from identified individuals were visually examined using Analook W (Chris Corben, 1999). Visual examination permits the elimination of low quality call sequences including distress calls, social calls, and other files that only include noise from further analyses.

Step 2: Suitable files were further examined on Anascheme (Matt Gibson, Ballarat University, unpubl.). Anascheme reads Anabat files and models individual signals within the file using regression analysis (Gibson & Lumsden, 2003; Law & Chidel, 2006). A regression model was fitted onto each signal and a total of 31 parameters can be extracted.

Echoes and other ultrasound nuisances can be recognised as signals if the model is misfitted. As a call sequence normally consisted of a variety of signal patterns, visually eliminating outliers was necessary. This also allows exclusion of other than the search phase of the call which is the most representative part of species-specific traits and is the only phase useful for echolocation identification. Anascheme calculates the level of model fit and any signal with the model quality less than 90% was excluded.

Step 3: Signal attributes were pooled for each species as species call characteristics. The attributes obtained from *N. geoffroyi* and *N. sherrini* were lumped together as *Nyctophilus* spp. due to indistinguishable call features. The classification tree software, C4.5 clone version, (Weka ver. 3.7.0.; Witten & Frank, 2005) was used to develop an identification key. Call parameters were chosen from the most frequently used in other studies on mainland conspecifics (Gibson & Lumsden, 2003; M. Gibson, unpubl. data). Slight modification of combinations of attributes were attempted to create keys to optimise the decisions. Finally, 12 attributes used to create a classification tree: *model curvature (Cur); duration (Dur); average time between pulses (AveTBP); end frequency (Fend); minimum frequency (Fmin); maximum frequency (Fmax); model frequency (Fc); model average frequency (Fmean); model slope (S); model end slop (Send); model start slope (Sstar); mean model curvature (Curmean).*

Step 4: Preliminary versions of the call identification key were tested on Anascheme against a set of reference calls that were used to create their own classification tree. Correctly identified calls were then used to extract attributes again, but only including correctly classified signals within the calls to improve the reliability of the key. This procedure was repeatedly conducted until all reference calls used were correctly identified with high confidence (i.e. >70% of signals in a call sequence correctly assigned to the same species).

Step 5: A set of unidentified calls was used to test the reliability of the key. 1007 unidentified call files collected by Inada (2006) were used. Anascheme does not read more than 1000 call files at a time, and hence the files were separated into two subsets of 500 files and 507 files for the test. The following options were set within Anascheme during the test. Identifications were only made when more than 50% of signals within a sequence were identified to the same species (i.e. confidence level = 50%), and only files containing more than five recognisable signals were identified and assigned to a category "Unknown".

4.3 Results

The number of bats caught during the night varied between 0 and 16 individuals. There were only a small number of bats captured and several individuals escaped before identification was made (Table 4.1 unknown category). No individuals of *C. gouldii* and *C. morio* were captured, and the only individual of *N. geoffroyi* captured escaped before recording; hence no reference call was obtained from these species during the fieldwork. 57 reference calls included *C. morio* (N=21) were supplemented (Table 4.1 & Fig. 4.1).

Table 4.1 Numbers of bats trapped and hand-released for the purpose of call recording. The number of individuals for supplemental calls is unknown; sources are presented in parentheses; BL = Brad Law, LC = Lisa Cawthen. Note that calls from *N. geoffroyi* and *N. sherrini* were lumped to a category NYSPP.

Species	No. of individuals	No. of calls recorded	No. of Supplement calls	Calls used for final classification	No. of signals used
C. gouldii	na	na	na	na	na
C. morio	na	na	1 (BL) 20 (LC)	12	656
F. tasmaniensis	2	3	na	2	28
N. geoffroyi	1	3	2 (LC)	3	61
N. sherrini	3	2	na		
V. darlingtoni	4	17	21	21	1152
V. regulus	4	3	13	10	574
V. vulturnus	5	17	na	8	330
Unknown	8	na	na	na	na
Total	**27**	**45**	**57**	**56**	**2801**

A summary of the mean signal attributes for species-specific calls is presented in Table 4.2 (see appendix iii for details). It can be seen that there is considerable overlap in attributes among all the species (Fig. 4.1 to 4.7). *F. tasmaniensis* can be clearly separated from others since it scores the lowest values in all attributes except curvature. *Nyctophilus* species typically have a vertical, near-straight call shape and this is seen to be true in Tasmanian *Nyctophulus* species with Cur = 1.32 (see also Fig. 4.3 & 4.4). For the *Vespadelus* species the mean values of the frequency parameters decrease along with body size increase, contrary to the increase in signal duration. The large standard deviations associated with the frequency parameters in the genus *Vespadelus* indicates high variability within species and *C. morio* is seen to overlap extensively in call characteristics with *Vespadelus* species.

Table 4.2 Summary of mean signal attributes ±SD from reference calls of six Tasmanian species/species group

	Cur	Dur (ms)	Average TBP (ms)	Fmin (kHz)	Fmax (kHz)	Fc (kHz)	Fmean (kHz)	Slope
C.morio	3.07±0.98	3.28±1.15	86.89±20.00	45.69±1.81	58.80±9.66	46.35±1.67	49.06±2.67	0.78±1.33
F.tasmaniensis	1.82±0.76	2.14±1.06	8.02±1.99	30.54±11.29	41.66±13.81	30.77±11.38	34.87±12.25	4.91±4.93
***Nyctophilus* spp**	1.32±0.29	2.23±1.12	69.15±21.46	39.90±5.66	64.88±12.32	40.41±5.35	50.79±6.75	9.76±5.77
V.darlingtoni	3.66±1.48	5.32±2.49	59.38±41.70	43.30±1.80	60.27±13.39	43.87±1.69	47.35±3.80	0.63±1.56
V.regulus	3.89±1.55	4.23±1.86	38.63±26.34	44.34±2.12	64.75±11.38	45.12±1.93	49.05±3.22	0.90±2.02
V.vulturnus	3.36±1.52	2.83±1.50	63.55±33.82	47.61±2.42	63.87±13.70	48.10±2.42	51.83±4.76	2.90±4.52

A sample of partial echolocation calls of each species was extracted from the reference calls and illustrated below in Anabat 6 format. Each call sequence represented a partial search phase in a call sequence typical to Tasmanian bats. Variability of the start frequency of signals can be easily seen. Figures were extracted using Analook ver. 3.3 (Corben, 2006) with functions setting of F7, compressed time (TBP is compressed), single smoothing, and division ratio of 16.

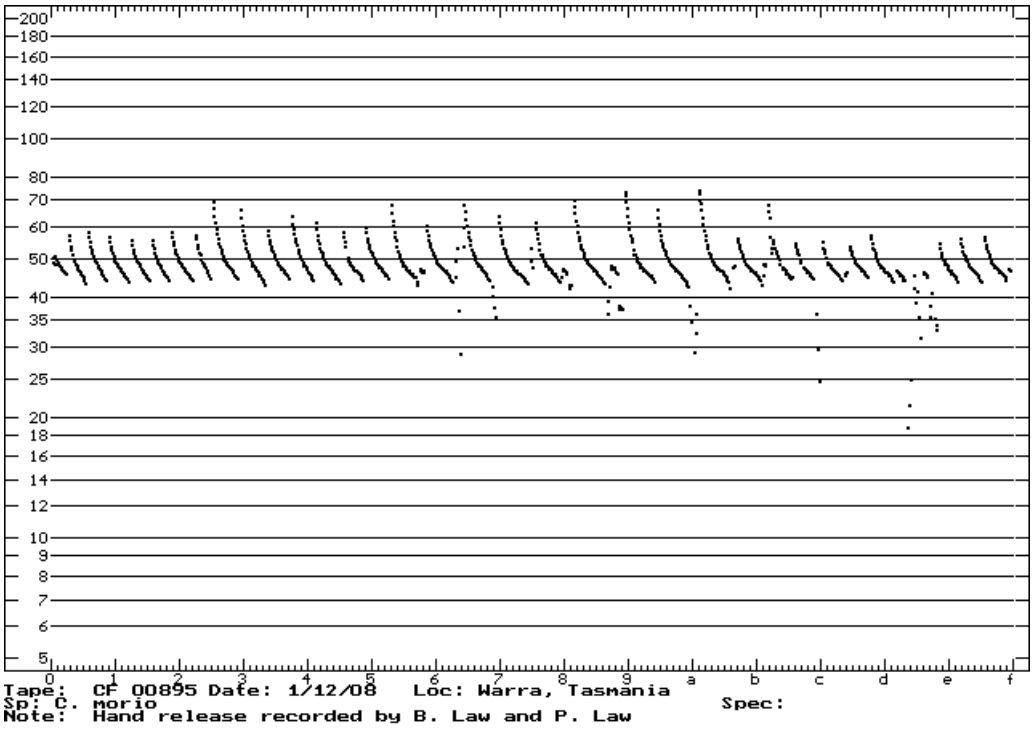


Figure 4.1 Echolocation call of *C. morio*

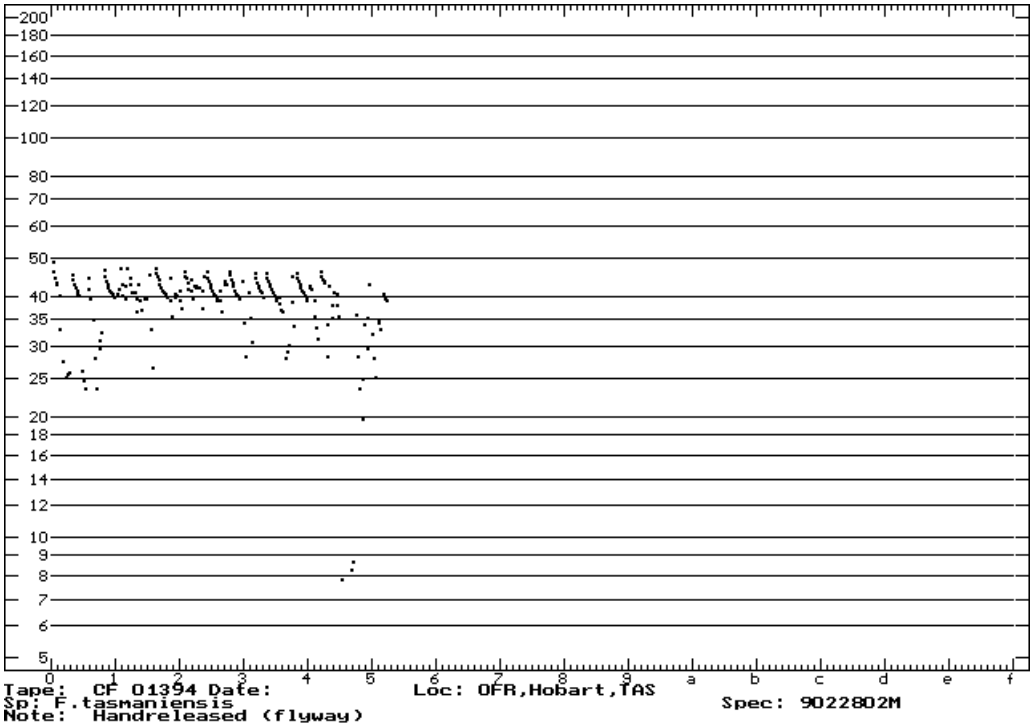


Figure 4.2 Echolocation call of *F. tasmaniensis*. Note the high signal to noise ratio and small number of call signals indicate less quality of the reference call.

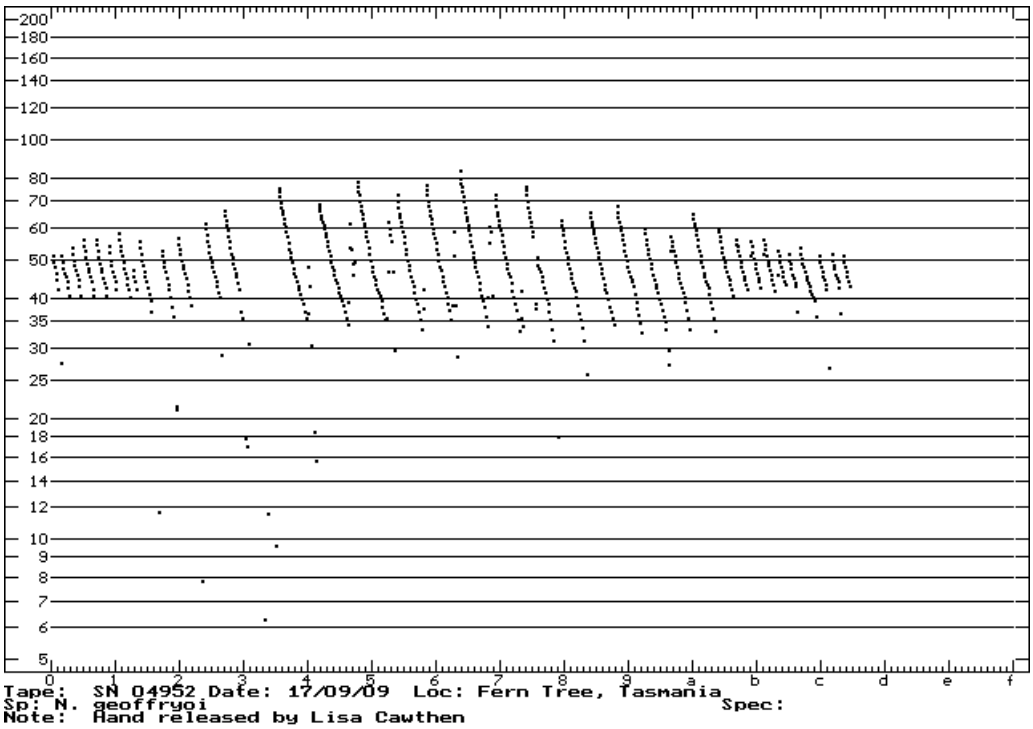


Figure 4.3 Echolocation call of *N. geoffroyi, r*esembles pattern and attributes of calls of *N. sherrini*

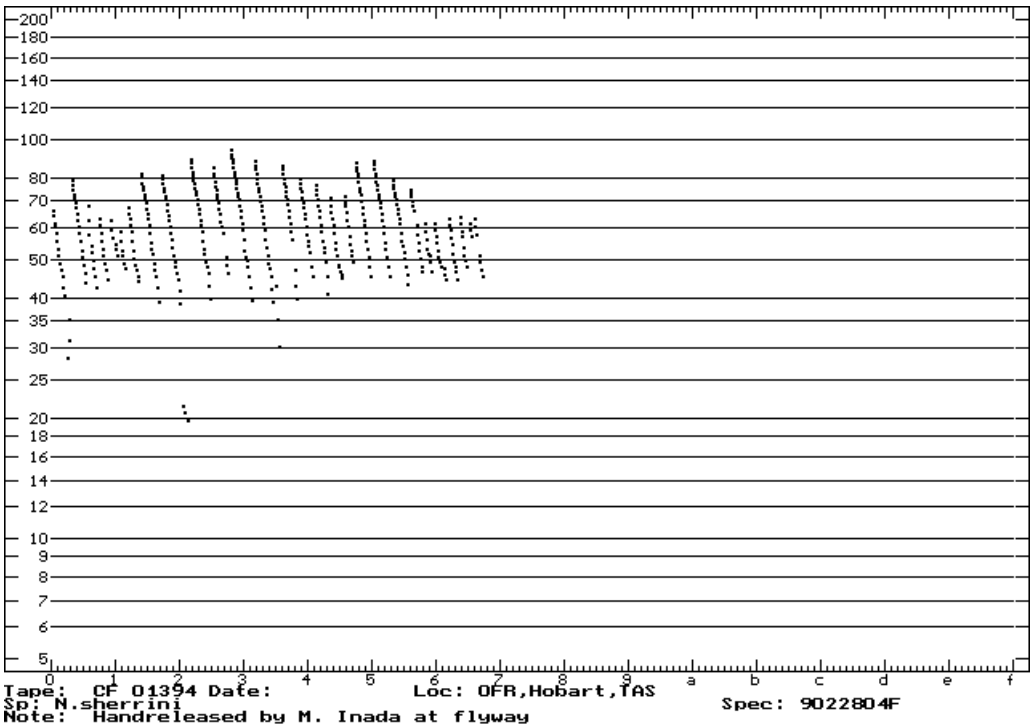


Figure 4.4 Echolocation call of *N. sherrini.* Resembling pattern and attributes of calls of *N. geoffroyi*

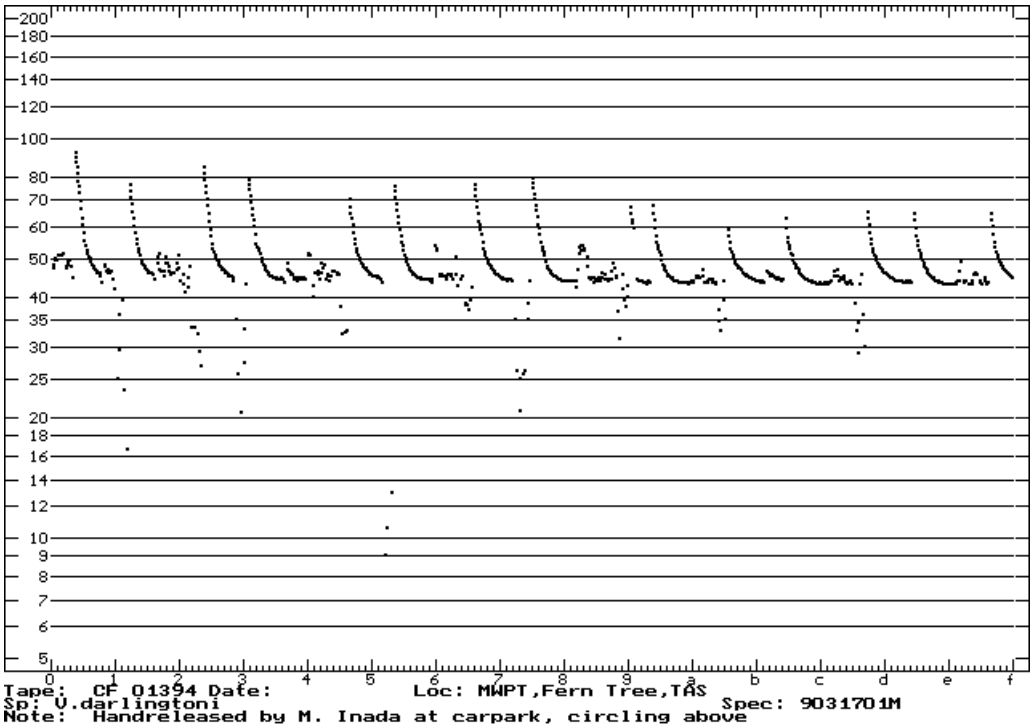


Figure 4.5 Echolocation call of *V. darlingtoni*

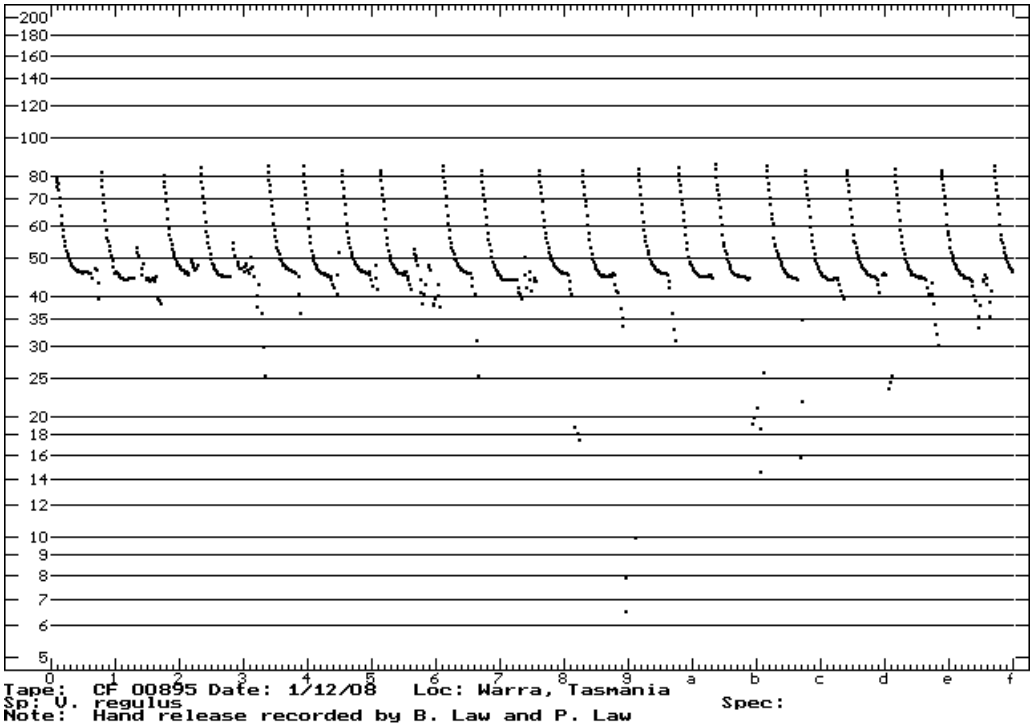


Figure 4.6 Echolocation call of *V. regulus*

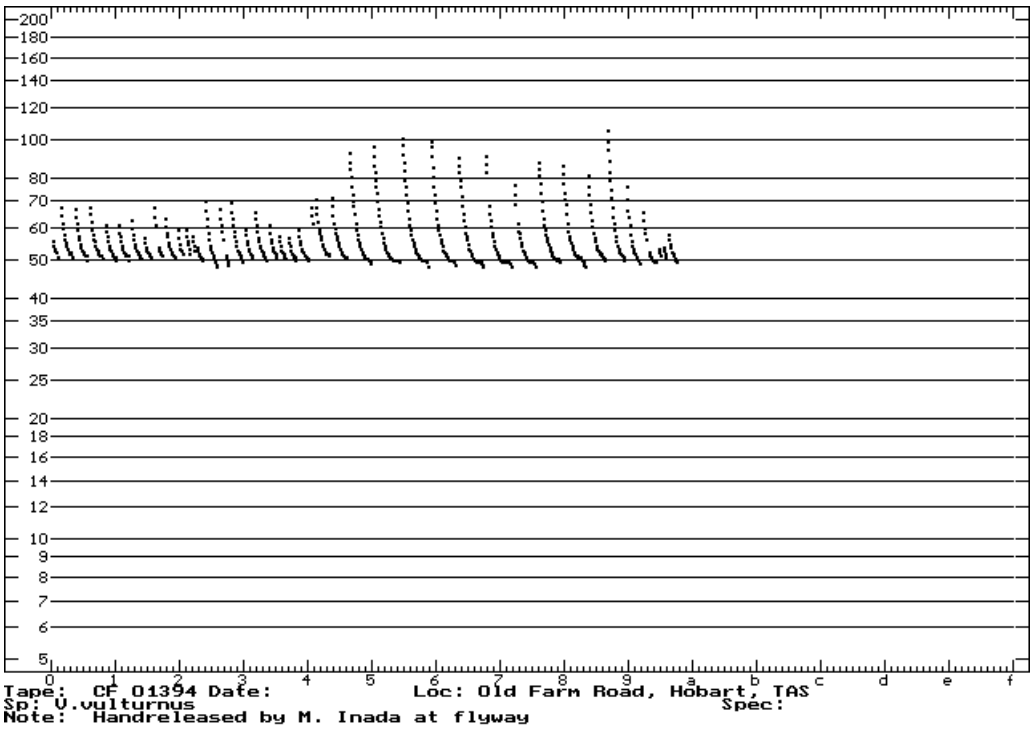


Figure 4.7 Echolocation call of *V. vulturnus*

The identification rate of reference calls using the key was 100%. The confidence of identification of calls scored between 71.4% and 100% against those call files.

A reliability test on 1007 unidentified calls, in two subsets, scored a lower identification rate. For the first set, the identification rate was 62.4% and 312 files were identified to one of six species; 188 files (37.6 %) were identified as unknown. In the second subset, the identification rate was slightly higher at 69.0% and the number of call files identified as unknown was 157. Minimum confidence levels of each subset were 54.7% (*C. morio*) and 55.6% (*V. regulus*) respectively. Total average identification rate was 65.7%. Overall identification rate of two sets of sample call files were summarised in Table 4.3.

Table 4.3 Rate of species identification on unidentified call sequences

Species category	No. of identified calls	Total identification rate (%)	Species ratio within identified calls (%)
C. gouldii	na	na	na
C. morio	51	5.07	7.70
F. tasmaniensis	44	4.37	6.65
Nyctophilus spp	60	5.96	9.06
V. darlingtoni	76	7.35	11.48
V. regulus	281	27.91	42.45
V. vulturnus	150	18.47	22.66
Identified total	662	65.74	100
Unknown	345	34.26	na
Total	1007	100	100

4.4 Discussion

Reference calls from hand-released bats showed the presence of typical FM calls for all species (Figs. 4.1 to 4.7). Body size is known to constrain call frequency, and high pressure sound at high frequency can only be produced by the vocal apparatus of smaller animals (Jones, 1999). Generally speaking, larger species produce lower frequency sound because the sound producing structures generate lower frequency as

linear size increases. Tasmanian bats appeared to follow this trend. The minimum and model frequency clearly increases in relation to decreasing body size. It is most apparent with the genus *Vespadelus* species. In comparison bats feed in clutter normally emit lower intensity echolocation pulses to mitigate the reflection of nuisance echoes in more complex habitats (Jones, 1999).

The echolocation calls of bats have evolved in response to particular acoustic environments, yet the patterns of echolocation do not appear to be defined by simple one-to-one relationships (Simmons *et al.*, 1979). Reference calls from *F. tasmaniensis* showed the species having much shorter average TBP than other species. This attribute does not significantly differ among mainland species (Herr *et al.*, 1997). Along with high variability of frequency attributes this is partly due to a small sample size (i.e. only two reference calls from two individuals were used and yielded just 28 signals). Signal interval is known to change greatly over time, situation, and presence of other bats and may not be as reliable a parameter as other call features.

High variability and overlapping features in frequency attributes within species of *V. darlingtoni*, *V. regulus*, and *V. vulturnus* with similar call characteristics with *C. morio* implies that their echolocation call in similar situations (e.g. flyways) can be misidentified, and call frequency parameters alone make cannot a good classifier for identification.

The failure to capture *C. gouldii* did not allow recording of call features of this species in Tasmania. Reinhold *et al.* (2001) reported slight geographic variation in *C. gouldii* in mainland Australia but it is negligible across south-eastern Australia (New South Wales and Victoria). *C. gouldii*'s search phase echolocation call is distinctive by frequency alternation of consecutive signals in the sequence (Reinhold *et al.*, 2001; Pennay e*t al*., 2004) and not likely to misidentified by visual classification. Characteristic frequency (= *model frequency* in Anascheme) is approximately 30 kHz, with 2 to 3 kHz difference between lower/upper sets of pulses. Tasmanian populations do not appear to greatly vary echolocation performances from mainland populations, having a similar characteristic frequency and pulse alternation pattern, and visually identifiable from all other species (B. Law, pers. comm.; Rhodes, 1996). The description of call features and comparisons of call characteristics between Australian mainland populations (Pennay *et al*, 2004; Churchill, 2008) and Tasmanian population are made below:

C. gouldii - appears to have no regional difference in Australia, having Fc within a range of 25 to 34 kHz, yet the echolocation characteristic of Tasmanian population is unclear.

C. morio - is known to have Fc between 46.5 and 53 kHz in Australia with down sweeping tail may be present. Tasmanian population demonstrated similar characteristics with having slightly lower Fmax (58.8 kHz). Fmax often exceeds 80 kHz in this species.

F. tasmaniensis - in Tasmania may have lower Fc (30.8 kHz) than the mainland population (35 to 39 kHz). This species do not show any down sweeping tail and Fmax approximately 60 to 70 kHz where as Fmax from Tasmania is slightly over 40 kHz. No geographic variation is known, but as the reference call of Tasmanian population was small and could not confirm the assumption.

N. geoffroyi and *N. sherrini* - are soft callers and relatively difficult to record quality calls. The echolocation characteristics of Tasmanian species appear to have no variations with other species in mainland. Shape of the pulse is distinctive and typical to the genus, steep, almost vertical and no curve hence no Fc. Often start at 65 to 80 kHz and then drop to between 35 and 47 kHz. Change in slope in the middle of signal may present in quality calls is reported in mainland Australia.

V. darlingtoni - in mainland population show Fc at 38 to 46 kHz and Fmax largely varies between 50 and 80 kHz while Tasmanian population having Fc at 43.9 kHz and Fmax at 60.3 kHz. Pulses are normally curved, and tails are absent or slightly up-sweeping.

V. regulus - has slightly higher frequency than *V. darligtoni*, as Fc of mainland populations are 40 to 55 kHz and 45.1 kHz in Tasmania. Call frequency and shape vary significantly among regions. Tail ends with up, up-then-down or down sweeping.

V. vulturnus - call shape is curved with almost always slight up-sweeping tail. Tasmanian bats can be having higher call frequency (Fc=48.1 kHz) than other populations (Fc=42.5 to 53 kHz). Fmax of the species is around 63.9 kHz in Tasmania. *V. vulturnus* are likely to change Fc up to 5 kHz during sequence. The increasing of call frequencies with decrease in body sizes in *Vespadelus* species is apparent in this study.

A number of problems associated with transforming the original call signal information by different bat detectors have been raised by Parsons *et al.* (2000). A combination of a frequency division system and a zero-crossing analysis method (i.e. the Anabat system) may also have these problems. It is apparent particularly when the signals are to be analysed qualitatively (i.e. visual examination) and the result is difficult to repeat (Parsons *et al.*, 2000). Also the result obtained from different sound analysis techniques are sometimes not comparable directly as the original call information may have been lost during transformation from the time domain to the

frequency domain.

When quantitative methods are employed to create keys for automated identification (e.g. for Anascheme), the parameters to be extracted must be carefully chosen. Different sound analysis programmes are able to extract different attributes such as a frequency of most energy (e.g. Parsons & Jones, 2000; Jennings *et al.*, 2008) that cannot be obtained from the Anabat system. Consistency of chosen parameters is a key to comparability of studies.

When different species encounter a similar situation, they may use similar calls (Rydell *et al.*, 2002) and the overlapping of echolocation calls is more apparent among morphologically similar species in such situations (i.e. *C. morio* and *Vespadelus* species). On the other hand, when diverse species from different niches are placed in the same situation they may still use different sonar signal patterns to perform the same task. This implies the patterns of echolocation calls are not strictly situation-based adaptations of a generalised form, but partly genetically determined (Simmons *et al*., 1978; Obrist, 1995).

High frequency suffers high atmospheric attenuation indicates that high frequency FM calls are only to function over a short range (Jones, 1999). Consequently, the FM call bats must produce broader width pulse at each emission with equivalent duration to call intervals. It is because of the FM call bats are incapable of Doppler-shift compensation (Jones, 1999; Neuweiler, 2000). FM calls typically begin with higher frequency, several octaves higher than the end frequency. The start frequency of reference call sequences, especially for those species which use steep FM calls, may not always be detectable and it can be difficult to interpret species-significance.

The minimum sound intensity required for detection of calls by detectors varies with situation and frequency. The echolocation call typical of the frequency used by the same species is not equally detectable in all habitats (Patriquin *et al.*, 2003). Attenuation by surrounding objects and ambient condition is complex, and the effect upon call detectability at a site cannot be predicted. One might expect that calls in denser forest to be more attenuated and less detectable, but this is not always the case (Patriquin *et al.*, 2003). Some species seem to be equally detectable across all habitats, while others are not (Patriquin *et al.*, 2003). *Nyctophilus* species emit low intensity calls (Pennay *et al*., 2004) and use passive detection when they come close to prey insects and this behaviour makes them less detectable.

Anascheme is an effective and quick mean of identification tool. It identified 500 call files less than three minutes. However, the accuracy of identification and the reliability is depending on quality of the classifier. Pre-processing of data to extract

attributes for classifiers is hence extremely important (Wilson, 2003; Jennings *et al.*, 2008). Even after careful adjustment of key and signals from reference calls lead to misidentification of unidentified calls, even though it may not be problematic when the call contains sufficient number of quality signals over less quality ones. It is apparent in cases such as fewer signals were involved in calls, less quality calls were available from sampled sites, and large numbers of species which have overlapping call features present. For example, in North American vespertilionids, percentages of usable signal in a call sequence varied between 60-80% (O'Farrell *et al.*, 1999). For collection of reference calls from identified individual bats, active rather than passive recording should be used to increase call quality.

There was no opportunity to comprehensively test the correct identification rate for the key due to a limited set of calls of known identity being available. Samples of 1000 unidentified call files were tested on Anascheme to obtain a rate of identification instead. The accuracy of correct identification with Anascheme among studies varies between around 25% and 70% (e.g. Gibson & Lumsden; 2003, Law & Chidel, 2006; Fischer *et al.*, 2009). Anascheme with the Tasmanian regional key identified 65.7% of those call files into one of six predefined taxa. This percentage falls well within the identification rate of other studies and hence identification with the key developed in the present study is argued to be conservative and reliable.

The correct identification rate varies with species, or even genera, regardless of the qualitative/quantitative methods employed (Jennings *et al.*, 2008). Improvement of the classifier, and hence rate of correct classification can be achieved by providing additional reference calls from known individuals of species. It is the number of individuals, not the number of calls from the same individual that is necessary to avoid pseudoreplication (Jennings *et al.*, 2008). In other words, repeated reference calls from long-captive animals are not valid unless previous calls are replaced by better quality calls. In this study, no individuals were kept in captivity and all reference calls were recorded by hand-released animals at the site, and hence pseudoreplication was avoided in obtaining reference calls.

As acoustical techniques are now widely used as a major survey method for bat communities, especially for collecting information for conservation and management planning, a standardised methodology for data collection is necessary for comparability and interpretation. Acoustic recordings by bat detectors are effective and efficient in terms of less time and fewer human resources required. However, species identification by echolocation calls requires a large amount of reference calls stored in a library. The mechanism of such intra-specific call alternations has not been comprehensive. The call

variation within the species often coincides with geographical boundaries, even though natural landscape features which are not always sharp barriers may offer some possible explanations of cryptic species; change in call frequency with morphology; changes in species assemblages; prey availability/ dietary differences; and interaction between above (Law, 2003). Variations in echolocation call can originate from three major causes: individuals capable of altering call characteristics according to their needs; intraspecific call variation between geographic areas; interspecific call variations can be less different in one region compared to intraspecific variations in different regions, and in this case the overlapping in call characteristic between species are extensive (Reardon, 2003). Flexibility in echolocation calls allows for more efficient perceptual performances during flight and hence more flexible species have access to a wider variety of environments (Obrist, 1995). Differences in the capacity to alter echolocation between species indicate different foraging flexibility and hence susceptibility to long term changes in their main foraging habitats (Obrist, 1995).

Chapter 5

Community composition and distribution of Tasmanian bat species

5.1 Introduction

Determining the distribution and abundance of animals associating with the causes is fundamental question and is high conservation importance as current understanding suggested the accelerating degradation of habitat and alternation of ecosystem are apparent to many organisms (Jaberg & Guisan, 2001). Examining coarse grained features of the landscape including latitudes and longitudes, elevation, and predominant habitat types is necessary for understanding broad distributions of animals (Warren *et al.*, 2000). Identifying distribution in bats requires a considerable amount of efforts due to nocturnal activity, wide home range and the difficulty to remote identification without aides. Alternatively, species-habitat relationship could be a useful tool to develop models to predict potential distribution from habitat descriptors (Walsh & Harris, 1996; Jaberg & Guisan, 2001; Milne *et al.*, 2004). The essential habitat requirements of bats, like any other animals, can be divided into two major components, foraging areas and refuges (Taylor & Savva, 1988). To predict accurate distribution of bats, these two components are necessary taken into account.

To estimate bat population in larger-scales considerable amount of information is required and predefined knowledge of; the precise geographic limits to the study region; the number and size of roost present in the study region; all roost needed to be located; dispersion range of individuals from the roost on daily and seasonal bases; migration rate of in and out of the study region (Thomas & La Val, 1988). Such information is not always available to most of area, but models could be developed from available data. Statistical modelling is an important management tool providing estimate of distributions of species and differentiation of habitat use.

There have been only handful researches available for Tasmanian vespertilionids distribution records (Taylor *et al.*, 1987; Rousevell *et al.*, 1991; Schulz &

Kristensen, 1996; Driessen & Mallick, 2003; Harris, 2005). Distribution of species remains unclear, as majority area in Tasmania has been unsurveyed. This is particularly for south-eastern Tasmanian and offshore islands, for instance the current project is the second source of bats reported from Bruny islands, since Woinarski (1986). Difficulty to determine the distribution despite of a large number of caves present, Tasmanian bat species do not utilise caves for roosts or hibernacula except occasional visiting, whereas some species on the Australian mainland often observed in caves colonies with large numbers (Churchill, 2008).

Habitat structure can have dramatic influences on amount of use by bats resulting in large differences in levels of activity detected among habitat types (Hayes, 1997). The object of studies comparing habitats by remotely sampling bats is to acquire a reliable index to their activity at a site. Bat detectors sample only a limited airspace, but the assumption is that this sample can be represent the index and be used to make inferences about the surrounding habitat adequately (Hayes, 2000; Weller & Zabel, 2002). Moreover, collecting data by remote bat detectors requires minimal working efforts, or more effectively collecting comprehensive inventory of species (Milne *et al.*, 2004). Factors that are influential on bat activity pattern and level of influence differ among studies implicating they might be area- and/or species-specific (Hayes, 1997), even though cumulative count of species at sites would illustrate species distribution.

Bat habitat relationship response is the one of most critical information gap which hinder management planing (Arnett, 2003; Ford *et al*., 2005). In Tasmania, basic knowledge about distribution and habitat use by different species is lacking to make management decision for bats community, except anecdotal observations and a small number of internal reports.

Mist-netting and harp-trapping have been conducted a number of times and there has been a general consensus of native bat species occur in Tasmanian, and acoustic survey is in particularly useful in terms of documenting known species to distribution survey. Counting species by acoustic recording, in regardless of bat abundance can be used to model the distribution of bats in relation of habitat and landscape parameters (Ford *et al.*, 2005). Accumulation of this type of information also helps to elucidate species specific-niche separation and provide insights for conservation and management which needed at larger scales (Ford *et al.*, 2005).

The acoustic methods allow collecting considerable amount of data which can be used to achieve different aims at the same time. Species presence/absence data which can be used for determining species distributions or developing distribution model (Milne *et al.*, 2003; Milne *et al.*, 2004), and amount of activity recorded at site, in

predefined habitat category, can be measure of habitat use of species (Thomas, 1988; Law *et al.*, 1998; Warren *et el.*, 2000). Population sizes and relative abundance cannot be estimated from the echolocation methods, yet with complementary to capture recorded from previous studies may allow to an inference of a broad idea of relative abundance.

Absence of species at sites did not imply that the species do not inhabit surrounding areas. Most of sites where data sampled were only one night survey. However, the combination of presence/absent data associating with environmental data particularly vegetation and forest types indicated species preferences and can be seen as potential indicator of distributions within Tasmania. Investigating potential changes in habitat use regarding impacts on habitat perturbation in larger-scale issues such as landscape best to be addressed by bats due to their ability to fly across various habitats and other taxa are influenced finer-scale in the system (Sherwin *et al.*, 2000).

It is important to study bats as communities because this is how they typically occur in nature, involving interactions between multiple species and their environment. Islands typically support fewer species of mammals perhaps due to limited resources and niche opportunities. Tasmanian bats may be of special interest because island communities of related animals may exhibit unusual features such as relaxed competition and niche broadening, as reported in honeyeater birds for example (MacArthur & Wilson, 1963; MacArthur & Wilson, 1967; Keast 1970).

The main aim of this chapter is to determine distribution of bat species within the state by investigating species-specific habitat requirements by using acoustic identification methods. Species inventory based on echolocation recordings were made in various environmental settings to reveal habitat-species relationships. Community data was also examined to see whether distribution and habitat use of a species is influenced by another.

5.2 Methods

5.2.1 Data sampling, sites, and variables

One or two of Anabat II ultrasonic detectors were deployed at sites on suitable nights and operated between sunset and sunrise. At some sites it was not possible to record over the entire night due to late arrival at sites, device failure, or disturbance during unattended periods. Anabat detectors were set on the ground, mostly angled toward the

sky at 45 to 90 degrees to gain the maximum detection of passing bats. Sensitivity of detectors was adjusted at sites just before recording to maximise the sound reception (Corben & O'Farrell, 1991). All acoustic sampling was conducted by static positioning.

Each call file recorded by the device was visually examined on Analook W ver.3.3 (Corben, 2006) to eliminate those which contained only non-echolocation signals (e.g. wind noise, insect calls, etc), prior to assigning automated call identification. Call files were then processed by Anascheme (Matt Gibson, Ballarat University, unpubl.) for identification to species (see Chapter 4). Identification of Anabat files was only attempted for those with more than five pulses in a sequence, and where pulses consisted of more than six pulse points (i.e. the Anascheme default setting). Conservative criteria were set to minimise the rate of misidentification of calls and to keep high identification confidence on Anascheme. Each call file was assumed to represent a single individual from a species and thus treated as an independent event regardless of the number of pulses or file length.

Acoustic recording was conducted over 62 nights at 36 sites. At each site the sampling effort varied between one night and eight nights. Six sites were sampled more than twice over a two year period. For these sites, data were pooled to obtain the mean values for number of calls and environmental variables. Activity indices of species (i.e. number of calls) were summarised as mean values, whereas presence/absence data for species was cumulative over multiple-night sites. Call data from within-site replicates (i.e. multiple night records) located less than 200m from each other were also pooled for analysis.

Sampling sites were not chosen randomly (see Chapter 3). However, a cross section of sites was covered, from closed flyways to near open fields, close proximity to residential areas to isolated areas and an elevation range from near sea level to over 700m. Habitat variables at each site were documented at sampling time from observation and supplemented by information extracted from existing public sources (Table 5.1). Forest types and vegetation classifications were obtained from two online databases, the Land Information System Tasmania (LIST) and TASVEG 2.0 (Department of Primary Industries and Water, 2009). Distance to the nearest water source in metres was estimated from the LIST maps. Altitude (from a GPS) and weather conditions were recorded at each site. For each site, climatic data including annual rainfall, the annual mean maximum temperature and the mean minimum temperature were obtained from the Australian Bureau of Meteorology website (www.bom.gov.au). Note that these latter data relate to the nearest major weather stations to the site, and the data may not exactly match the actual sampling site.

Sample nights were also not chosen randomly. Adverse weather conditions including heavy rain, strong winds and a rapid drop in ambient temperature are known to degrade the efficacy of echolocation survey methods and may also reduce the activity of bats (e.g. Law *et al*., 1998; Fischer *et al.*, 2009). Consequently, those nights were avoided from conducting observation.

Table 5.1 Habitat variables documented for sampling sites

Habitat variable	Source	Units/values
Forest group	The LIST	Hardwood plantation; Softwood plantation; Tall eucalypt forest; Low eucalypt forest; Other native forest; non-forest vegetation
Forest type	TASVEG 2.0	11 types (vegetation attributes in TASVEG 2.0)
Altitude	GPS	meters ASL
Distance to water	The LIST	meters from recording point to nearest open water source (both fresh/salt water)
Annual Rainfall	BoM	mm
Mean annual maximum temperature	BoM	°C
Mean annual minimum temperature	BoM	°C

Weather conditions were recorded at the beginning of observations (late dusk) at most of sites, although on a few occasions cloud cover and precipitation levels could not be measured as these were estimated visually. Three variables: ambient temperature (°C), relative humidity (%), and average wind speed (m/s) were recorded using a

Kestrel portable weather meter at the sites. Ambient temperature varied between 7.0°C and 25.8°C (n = 59 nights: mean±SD = 15.9±3.7°C); relative humidity varied between 34.9% and 100% (n = 59 nights: 71.2±13.6%); and average wind speed was between 0.0 m/s and 3.0 m/s (n = 56 nights: 0.46±0.69 m/s).

5.2.2 Analyses

1) Descriptive analyses

Descriptive data analyses were conducted for overall species occurrence, species richness, and species composition. The number of calls for each species was counted at each night and at each site. Presence/absence of species was then documented for each night and site. Proportions of the number of calls for species were compared to the proportion of capture rates of species in Taylor *et al.* (1987). Statistical comparisons between overall numbers of calls for the species are not adequate to estimate the relative abundance of the species, and hence no statistic analysis was conducted for this purpose (Hayes, 1997).

Species occurrence, species richness and composition were examined using presence/absence records for each night and site. Assemblages of species at sites were described by the presence of species. To gain an insight of species assemblages, Spearman's rank correlation was used to check pair-wise relationships between occurrences of species. Species occurrence was presented as a percentage of presences per overall night/site. Species richness was expressed as the total number of species per night or per site.

2) Habitat use

Habitat use of species was analysed by reference to vegetation types based on the TASVEG 2.0 classification scheme (Department of Primary Industries and Water, 2009). The relationship between species and forest habitat is of particular interest and has been studied previously by bat capture surveys in Tasmania. To examine the species-specific habitat usage, an activity index (i.e. the number of call per species per habitat) was used for analysis. An activity index has been previously used as a measure of use of habitat by bats (e.g. Law *et al.*, 1998; Grindel & Brigham, 1998; Avila-Flores & Fenton, 2005; Ford *et al.*, 2005). Prior to habitat analysis, correlations between the species activity index and weather conditions (i.e. ambient temperature, % relative humidity, and average wind speed) at the beginning of the observation were checked for all nights. No variables were strongly correlated with activity levels of species, but *V. regulus* and

"unknown calls" were negatively correlated with average wind speed (Spearman ρ = - 0.31, Prob = 0.02 and Spearman ρ = - 0.31, Prob = 0.02, respectively). This assumed that the data was sampled on nights which fell within the preferred range for bat activity.

Sampling effort varied among sites and hence forest habitats. First of all, the length of recording in each night varied from half an hour to the entire night, and recording duration significantly positively correlated with the activity index for four out of six species. A slight positive correlation was recognised with total activity index of all species combined (Spearman ρ = 0.25, Prob = 0.056). Since observations were conducted at different times of the year, the sample date was also checked against the activity index of each species. Date was not significantly correlated with species observations, except for *V. vulturnus* (Spearman ρ = 0.35, Prob < 0.05; data sampled from entire night observations only were used for the analysis). Because of large differences in activity index between species and lack of confidence in equal detectability among species, habitat use was compared within species only. Activity records were not normally distributed and there was a high proportion of zero values in the data; no transformation of data was conducted so non-parametric tests were used where appropriate.

3) Distribution

As identifying species distribution was a primary concern of the project, data from all observations were retained at first, regardless of recording conditions.

Adverse weather conditions such as heavy rain and strong wind reduce the activity of bats including emergence and foraging opportunity, and hence affect the recording of presence-absence of species, particularly in single night surveys (e.g. Taylor & Savva, 1988; Law *et al*., 1998; Fischer *et al*., 2009). Previous analysis has considered the effects of weather and it was safe to conclude that the presence/absence of species was not influenced by those factors in my study due to selection of sampling nights. Moon phases were not included in the analyses as a number of studies agree that activity of temperate bats appears not to be strongly influenced by moon phase, or the hour of moonlight (Rhodes, 1996; Hayes, 1997; Karlsson *et al.*, 2002; Russo & Jones, 2003), and so I assumed that the effect of moon phase was negligible. Consequently, these factors are omitted from further analyses.

For each species occurrence, the correlation between habitat variables was tested using Spearman rank correlation. Where pairs of variables have a correlation coefficient greater than 0.8, one of the pair is randomly excluded from further analysis

(Milne *et al.*, 2006) in order to seek the most parsimonious combination of descriptors for each species (i.e. reduce colinearity in the data). Then a generalised linear model (GLM) was used to seek a predictive distribution model based on species-habitat relationships (Milne *et al.*, 2006).

To explore the contribution of environmental variables to the presence/absence of bat taxa a logistic regression using the glm function and logit link function was fitted using the statistical programme R. The R code used was as follows (using FATA as an example):

```
> FATA <- glm(FATApa ~ East + North + MeanRain + RainDays + TempMax + TempMin
+ TempMean + Elevat, family = binomial, data = Masabats)
> anova (FATA, test = "Chisq")
```

This yields an Analysis of Deviance table with p values for each term. This method can be sensitive to the order in which terms are entered into the model, so terms were entered in reverse order as well in order to see if results were stable.

4) Community data

The relative similarities between bat assemblages at the sample sites were displayed in ordinations generated by non-metric multidimensional scaling (nMDS). Activity data was log (x+1) transformed before analysis to down weight the influence of very common species. The Sorenson Index was used for comparisons and the default options employed within PC-ORD (McCune & Mefford, 1999). Suitably low stress values were usually achieved in 3 dimensions. Environmental variables significantly correlated with the ordination were plotted as vectors in the ordination space. For these, a cut-off value of R = 0.2 was used.

A non-parametric multi-response permutation procedure (MRPP) was used to test the hypothesis of no difference between the sites (McCune & Mefford, 1999). This has the advantage of not requiring assumptions (such as multivariate normality and homogeneity of variances) that are seldom met in ecological data of this sort. The MRPP statistic *delta* is simply the overall weighted mean of within-group means of the pair-wise dissimilarities among sampling units.

5.3 Results

1) Descriptive analyses

Static remote acoustic recording of bat calls was conducted at 36 sites over 62 nights for a total of approximately 516 detector hours. Preliminary visual examination on all files resulted in 7,889 computer-generated files which contain at least three recognisable echolocation signals in a sequence. Anascheme successfully classified 80.7% (i.e. 6371 calls) of recognised files to one of six species or species groups. The remainder were classified as unknown, reflecting the extent of overlaps in the call parameters of species and poor quality of some call sequences.

Over two summer periods, the occurrence of most species was high at most sites (Fig. 5.1). There was a slight decrease in the proportions of species presence in the per night occurrence than the site occurrence as the latter was obtained by aggregating night observation at the same sites. Four species were especially widespread among the sample sites: *C. morio* and all three *Vespadelus* species were represented in more than 80% of both nights and sample sites. Most prevalent of all the species was *V. regulus*, recorded at all sites and on 93.6% of nights, followed by *V. darlingtoni* (sites = 97.2%; nights = 92.1%). *F. tasmaniensis* was observed least often, recorded at less than 20% of sites (sites = 19.4%; nights = 17.5%).

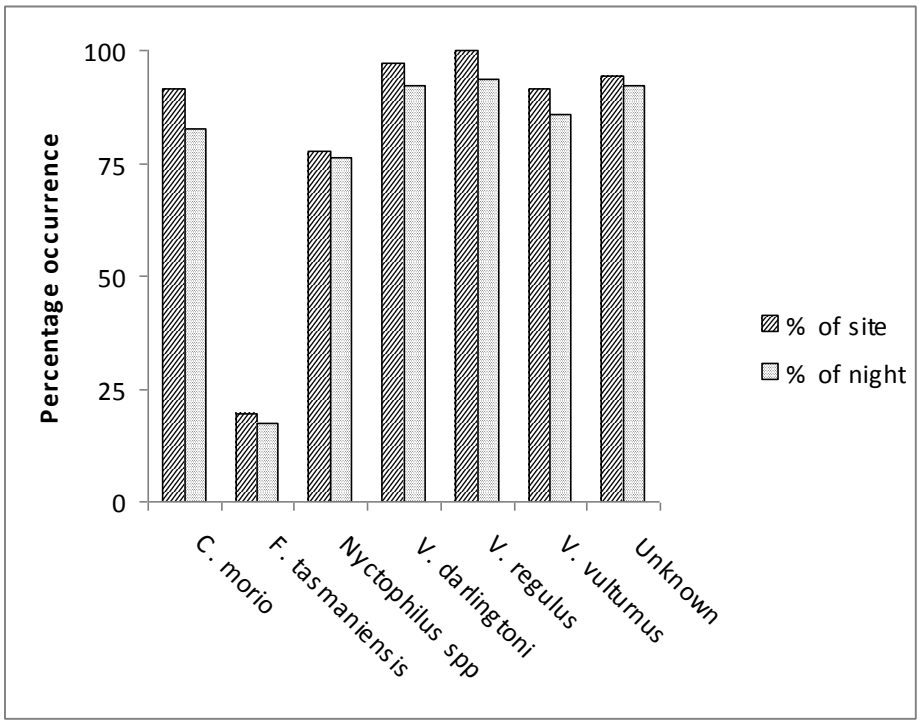


Figure 5.1 The representation of Tasmanian bat species for total sites and nights.

Overall, bat species richness was relatively high at most observation points. More than five species were recorded on two thirds (67.7 %) of nights and 69.4 % of sites, and 80.65% nights and 91.67% sites were observed more than four species at the time. The minimum species number recorded was one species at Woodbridge in January, 2008 but this was associated with a much shortened recording time = 2.5 hrs. Five species were most commonly recorded, occurring at half the sites (n = 18). On the other hand, the maximum number of taxa was recorded at slightly less than 20% of sites (Fig. 5.2).

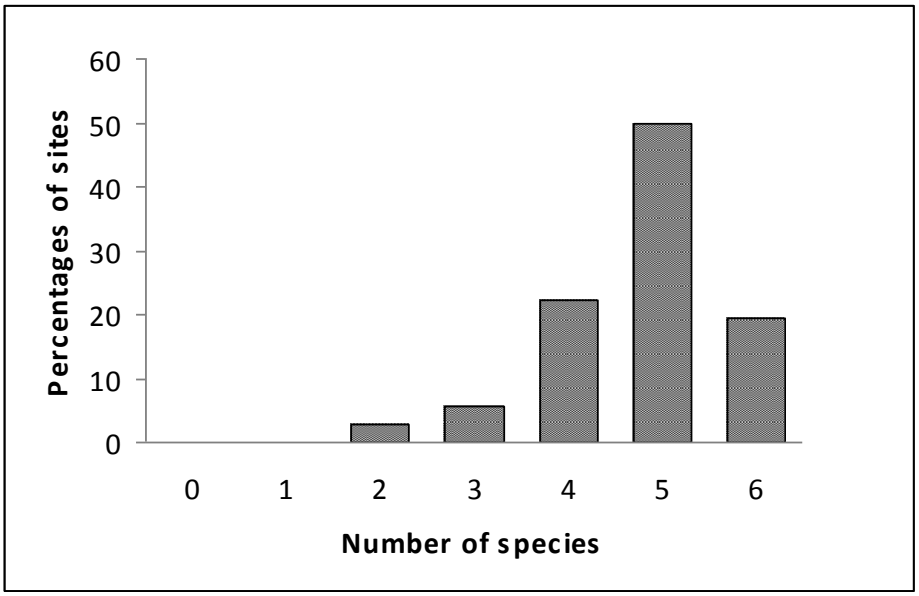


Figure 5.2 Number of species observed at sites (all nights combined). A number of sites are expressed in proportions.

Presence/absence records of species at the sites are summarised in Appendix iv, which also shows actual species composition at the sites. Spearman's rank correlation identified seven pairs of species which significantly correlated on co-occurrence (Table 5.2). Levels of correlation were, however, low to moderate (Spearman $\rho = 0.25$ to 0.68). *C. morio* and *V. vulturnus* presence, due to their relative ubiquity, were most commonly correlated with other species presence, while *F. tasmaniensis* and *V. darlingtoni* did not appear to be affected by other species presence. Among all combinations, only two taxa were very slightly negatively correlated, *V. darlingtoni* and *F. tasmaniensis* (Spearman $\rho = -0.01$), and presence of unknown calls and *V. darlingtoni* (Spearman $\rho = -0.07$), but not significantly ($p>0.05$); all other combinations were at least weakly positive.

Table 5.2 Correlations of presence of species at night observations. Species pairs with significant correlation identified by Spearman's rank correlation.

Pairs of species presences correlated		Spearman ρ	Prob>|ρ|
Nyctophilus species	*C. morio*	0.3551	0.0046
V. regulus	*C. morio*	0.4855	<.0001
V. vulturnus	*C. morio*	0.5769	<.0001
V. vulturnus	*Nyctophilus* spp.	0.2524	0.0478
V. vulturnus	*V. regulus*	0.5859	<.0001
Unknown calls	*C. morio*	0.5655	<.0001
Unknown calls	*V. vulturnus*	0.6823	<.0001

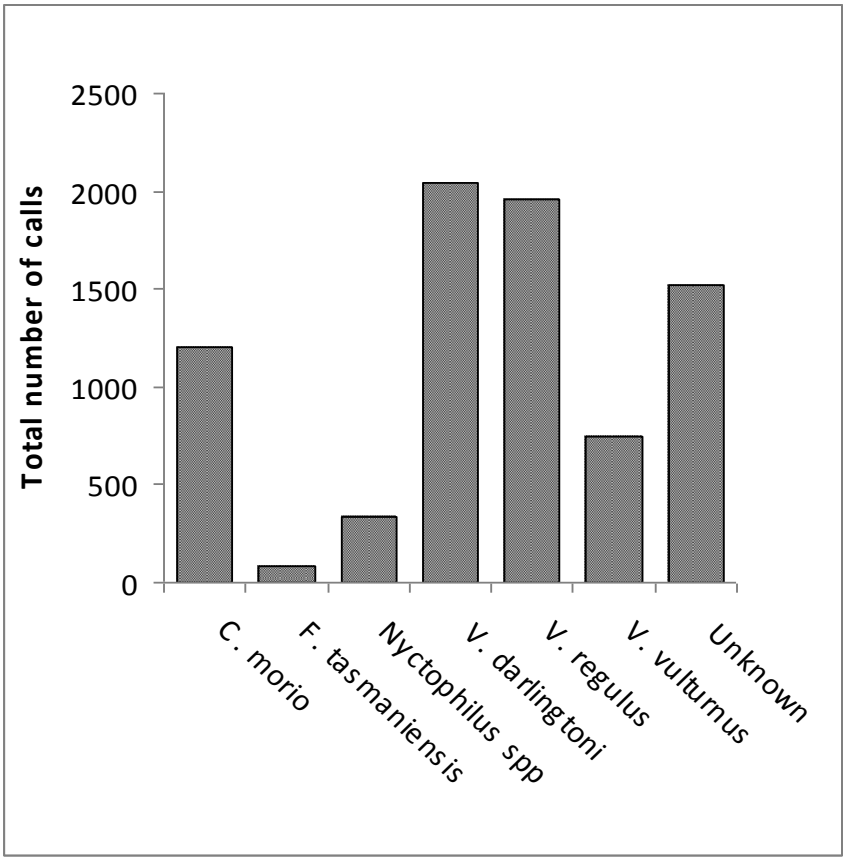


Figure 5.3 Total number of calls per species recorded during the study (all data combined).

All identified calls for each species were pooled together and their relative dominance is shown in Figure 5.3. Four species had more than 500 passes recorded,

while *F. tasmaniensis* only recorded 80 passes which represented only 0.87% of all records. The relative proportions for other species were; *C. morio* 15.40%, *Nyctophilus* species 4.25%, *V. darlingtoni* 25.93%, *V. regulus* 24.88 %, and *V. vulturnus* 9.42%. Almost one fifth (19.24%) of call files contained bat signals that failed positive identification.

2) Habitat use by species

Wilcoxon tests failed to find any statistically significant differences in mean AL between habitats for each species and thus failed to detect any strong differentiation in habitat use in each species. This outcome was apparent despite uneven sampling effort by habitat type. The mean activity index for each species for each habitat is presented in Table 5.3. The large standard deviation indicates that effects of sites/night fluctuations within habitats were extensive.

Four species use all habitats to some extent with some degree of variability (Fig. 5.4) but the large standard deviations (see Table 5.3.) indicate that the veracity of the following trends require further testing. *C. morio* is most commonly associated with wet sclerophyll and scrub habitats. *V. darlingtoni* is found in urban and moorland habitats more often than other *Vespadelus* species, whereas *V. vulturnus* strongly associates with non-eucalyptus forests. *F. tasmaniensis* and *Nyctophilus* species showed somewhat skewed habitat uses with preferences towards non-eucalyptus forests. *F. tasmaniensis* was not observed to be active in urban and scrub habitat which is contrary to the idea that the species prefers open and less cluttered habitats.

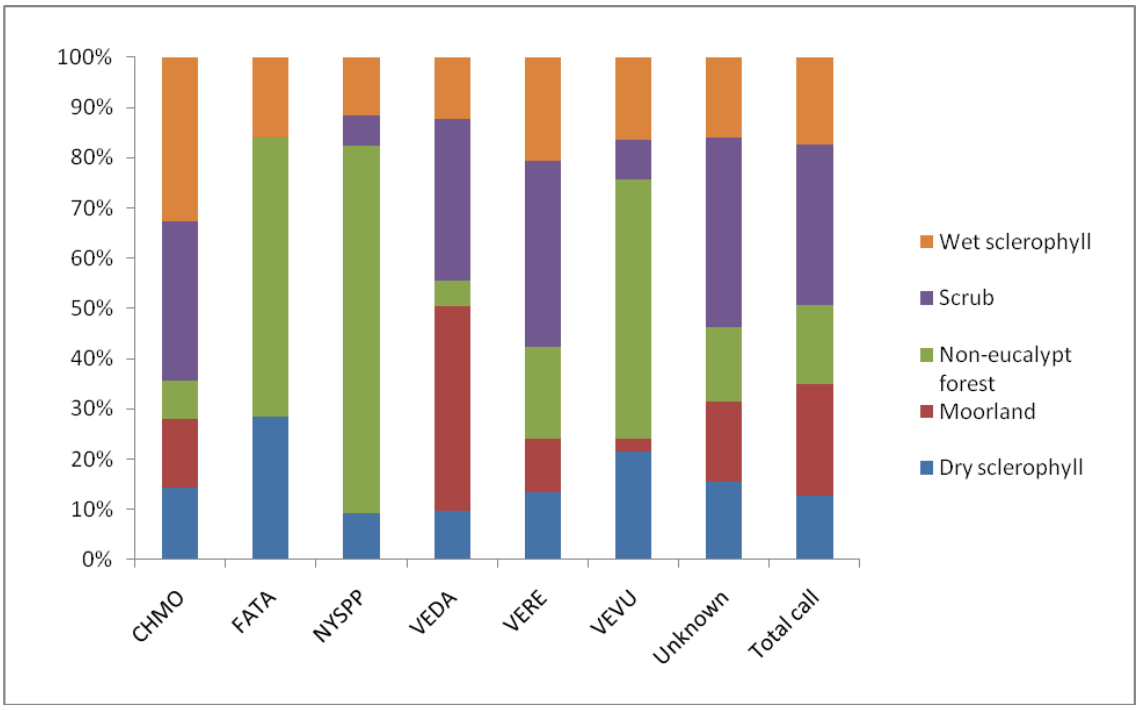


Figure 5.4 Proportions of the mean passes of each species in different habitat types based on dominant vegetation. All nights and sites aggregated. CHMO = *C. morio*, FATA = *F. tasmaniensis*, NYSPP = *Nyctophilus* species, VEDA = *V. darlingtoni*, VERE = *V. regulus*, VEVU = *V. vulturnus*.

Table 5.3 Comparisons of habitat use of species in five broad vegetation types in Tasmania. Mean activity index with ± SD was presented. Wilcoxon tests were used. Note the different sampling effort in habitats, only single observations were made in Moorland, Non-eucalyptus forest, and twice in Scrub habitat. The test failed to detect significant differences in the use of habitat in all species.

Species	Dry sclerophyll (df = 26)	Moorland (df = 1)	Non-eucalypt forest (df =1)	Scrub (df = 2)	Wet sclerophyll (df =11)	X^2	p
C. morio	22.04 ± 28.64	13.00	7.00	30.00 ± 33.94	30.00 ± 35.11	0.4	p = 0.98
F. tasmaniensis	2.42 ± 6.70	0.00	1.00	0.00	0.46 ± 0.82	2.58	p = 0.63
Nyctophilus species	6.46 ± 8.91	0.00	30.00	2.50 ± 0.71	8.36 ± 10.17	6.82	p = 0.15
V. darlingtoni	28.96 ± 31.87	124.00	15.00	98 ± 53.74	21.27 ± 33.84	7.31	p = 0.12
V. regulus	38.19 ± 65.51	20.00	34.00	68.50 ± 68.59	41.18 ± 42.32	2.56	p = 0.63
V. vulturnus	18.54 ± 27.98	1.00	20.00	3.00 ± 1.41	11.91 ± 11.48	4.05	p = 0.40
Unknown	25.96 ± 23.22	29.00	27.00	68.50 ± 65.76	25.36 ± 19.83	2.29	p = 0.68
Total activity index	**142.35 ± 143.28**	**187.00**	**134.00**	**270.50 ± 156.27**	**138.55 ± 101.28**	**3.66**	**p = 0.45**

Correlations between species richness and a cross section of environmental attributes and variables were generally low. Species richness increased weakly with northing and elevation, and was unresponsive to mean annual temperatures and rainfall. As expected, temperature at set-up was significant.

Table 5.4 Correlations of species richness of bats with a range of environmental variables recorded for sites. * p<0.05; ** p<0.01; ns not significant.

Variable	Correlation	P
Northing	0.209	*
Easting	-0.038	
Elevation	0.226	*
Mean annual temperature	-0.061	ns
Mean annual minimum temperature	-0.122	ns
Mean annual maximum temperature	0.003	ns
Temperature at set-up	0.254	*
Mean annual rainfall	0.133	ns
Night length	0.105	ns
Total calls per night	0.480	**
Calls per hour	0.248	*

Logistic regression failed to uncover any significant influence of environmental variables on the presence/absence of bat taxa. Table 5.5 shows the outcome for *Falsistrellus tasmaniensis* as an example.

Table 5.5 Analysis of Deviance Table for *Falsistrellus tasmaniensis* (FATApa) following logistic regression. Model: binomial, link: logit. Terms added sequentially (first to last).

Variable	df	Deviance	Resid df	Resid.Deviance	P(>|Chi|)
NULL	35	35.467			
Easting	1	0.160	34	35.308	0.689
Northing	1	0.453	33	34.855	0.501
Annual Mean Rainfall	1	0.132	32	34.722	0.716
Annual Rain Days	1	2.787	31	31.935	0.095
Annual TempMax	1	1.446	30	30.489	0.229
Annual TempMin	1	0.007	29	30.482	0.935
Annual Temp Mean	1	0.019	28	30.462	0.889
Elevation	1	1.128	27	29.334	0.288

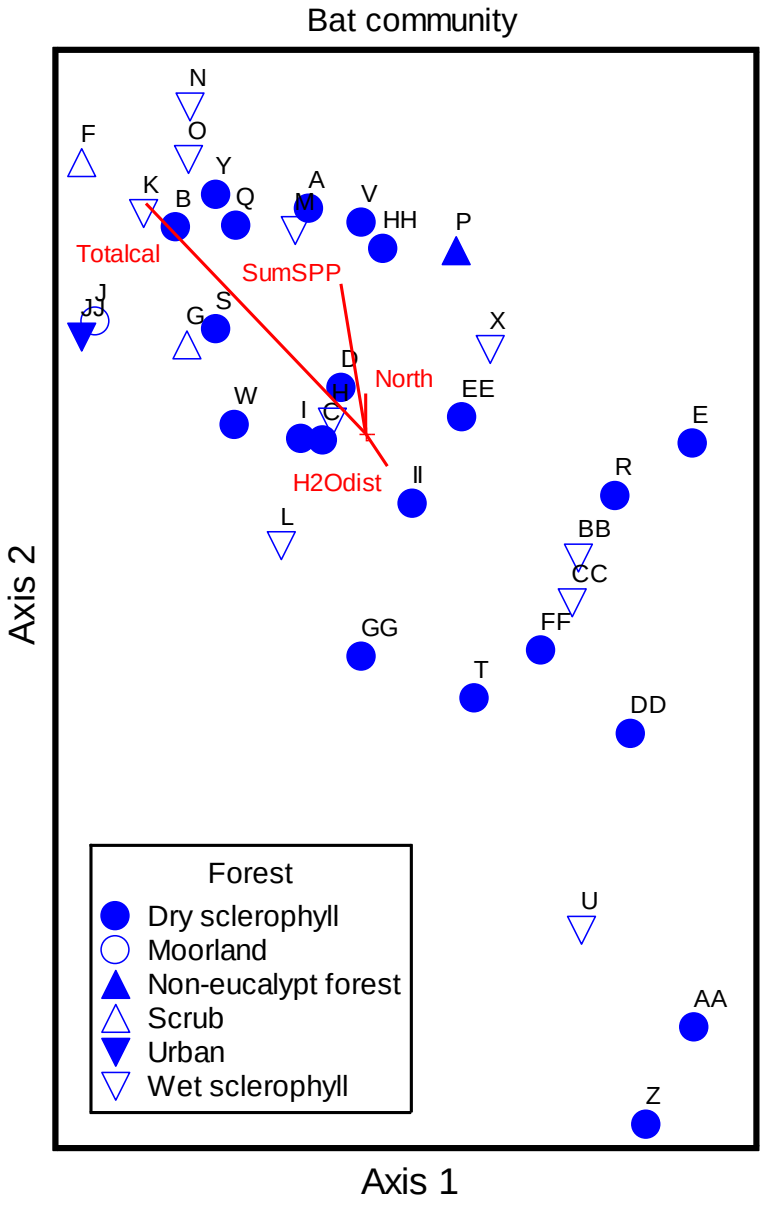


Figure 5.5 Ordination (NMDS) of individual sampling sites and habitats based upon the community of bat species present. A cut-off value of 0.2 was used for variables fitted as vectors in the ordination space. Stress in 3 dimensions = 13.4%.

Table 5.6 MRPP results for vegetation types with multiple examples.

Vegetation type	n	Average distance (in group)
Dry sclerophyll forest	21	53.44
Non eucalypt forest	2	132.26
Wet sclerophyll forest	10	83.50

Test statistic: T = - 0.271.

Observed delta = 67.334 (Probability of a smaller or equal delta, p = 0.339).

Chance-corrected within-group agreement, A = 0.0086

[A = 1 - (observed delta/expected delta)

Amax = 1 when all items are identical within groups (delta = 0)

A = 0 when heterogeneity within groups equals expectation by chance

A < 0 with more heterogeneity within groups than expected by chance]

The ordination of bat communities (Fig. 5.5) shows that there was very weak differentiation of communities among the habitat types. In other words, Tasmanian bat communities show a low response to vegetation type, at least over the range of habitats sampled in this study. The non-parametric multi-response permutation procedure (MRPP) supported the hypothesis of no difference between the three forested vegetation types in terms of their bat fauna (Table 5.6).

5.4 Discussion

The data collected in this survey offers insights into the distribution of six taxa of Tasmanian bats and their degree of association with some aspects of their environment. However, it should be noted that the acoustic data only consisted of search phase calls that only represent a portion of bats' activities.

Most species were observed on most of the nights and at most sampling sites across a range of vegetation types, except *F. tasmaniensis*. Opportunistic habitat use in Tasmanian vespertilionids was also suggested to be common by Taylor & Savva (1987) and is reported from other temperate regions (e.g. Hayes, 1997). Unlike many other small terrestrial animals, their high agility and capacity for long distance flight without major difficulty enables them to exploit large habitat areas spanning several kilometres (e.g. Lumsden *et al.*, 2002; Churchill, 2008). In this sense, sample sites unavoidably represent a single point which may only represent a small proportion of a bat's habitat.

The relatively high local species richness apparent at most sites agrees with findings from previous studies (e.g. Taylor & O'Neill, 1986). In my study, only six species/species group could be distinguished from echolocation data, but call recordings classified as unknown were present in nearly all observations. Thus *C. gouldii* could well be present among those observations and hence slightly higher species richness could be present.

It can be concluded that the Tasmanian bat community assemblage appears to be highly sympatric at local scales. A local species richness of five taxa was the most commonly found and a few sites in my study were observed to have six taxa. Pairwise tests of species revealed that *C. morio* and *V. vulturnus* are most positively correlated with other species, but this probably reflects their ubiquity. *V. darlingtoni* and *V. regulus* were the most commonly detected species, present at virtually nearly all sites regardless of habitat.

The proportions of each species making up the community, in relation to total number of calls recorded, can be argued to reflect the relative abundances of the species. Population size and relative abundance of the species cannot be estimated by acoustic sampling alone (Thomas & LaVal, 1988; Hayes, 1997; Humes *et al.*, 1999). However, it can be used as a predictor to obtain a general idea of relative abundance when complementary data from other methods are available. Even though *C. gouldii* could not be identified and *Nyctophilus* species were combined in my study, the rank order of species proportions I found was similar to that detected by other authors using different technology. Previous studies reported the proportions of Tasmanian species captured as: *C. morio* 20%, *C. gouldii* 2%, *F. tasmaniensis* 7%, *N. geoffroyi 10%*, *N. sherrini* 3%, *V. darlingtoni* 12%, *V. regulus* 35%, and *V. vulturnus* 11% (Taylor & O'Neill, 1986; Taylor *et al.*, 1987).

Interpretation of the relative abundances of *F. tasmaniensis* and *Nyctophilus* species presents special challenges due to aspects of their acoustic behaviour. *F. tasmaniensis* emits lower frequency FM calls which can extend a longer distance, but these bats fly at higher altitudes, normally above the canopy, and the call may not readily penetrate through thick canopy cover. High altitude flight is also problematic for harp-trapping which will be only able to capture those bats which come close to the ground for drinking or commuting. Hence, a low occurrence of records, by either traps or acoustic recording, may only reflect difficulties associated with their behaviour. *Nyctophilus* species, on the other hand, are less difficult to capture by traps as they commonly associate with shrub-like vegetation for foraging. However, these bats are known to use passive listening in their hunting strategy. During passive listening they do

not emit echolocation calls. As well, *Nyctophilus* species emit low intensive sound calls at relatively higher frequency. This combination of acoustical properties could minimise the detectability of *Nyctophilus* species, even those flying in close proximity to the detectors. *F. tasmaniensis* was generally only recorded where all other species were present, except for one night when only *V. regulus* and *V. vulturnus* were observed. As a fast, high altitude flier, *F. tasmaniensis* was the least captured species in previous studies also. Despite of its wide distribution throughout eastern Australia and Tasmania, *F. tasmaniensis* is the one of least studied species of bats and the repertoire of its echolocation call is not well known (Pennay *et al.*, 2004).

Analysis failed to find evidence for any strong differentiation in species-specific habitat use. No evidence of strong relationships between species distribution and forest type was found. Despite of methodological concerns, undifferentiated use of forests as commuting and foraging habitats has been reported in a number of studies (e.g. Taylor *et al*. 1987; Law *et al.,* 1998; Grindel & Brigham, 1998). Bats can fly over a mosaic of habitats without much difficulty and can do so in a relatively short time. The dispersion of potential commuting/foraging habitats such as observed in this study may make it difficult to appropriately measure the full extent of habitat use. Dynamic use of a variety of habitats for separate behaviours (i.e. foraging vs. roosting) makes assessment of habitat use by bats difficult.

Subtle differences in habitat use by various species may in fact occur but not be detected by this study. Intensive small scale study at numerous sites would be needed to detect this and represent a considerable challenge. Some differences in the community revealed in the ordination could be interpreted as evidence of subtle differences in habitat use but for the time being, are better interpreted as natural variation within the broader tolerances of communities. In moorland, scrub habitats *V. darlingtoni* showed high activity levels. A large number of passes in scrub habitat was also seen for *V. regulus*. For unknown reasons, in scrub habitat the number of unidentified calls was as twice high as other habitats. It is possible that one of the sites was close to a roost which was located in an attic. Calls recorded in late January could be non-search phase calls including social calls of juveniles. *F. tasmaniensis* activity was only observed in forest habitats. The single observation of this species in non-eucalyptus forest was also the sample with the highest proportion of this species. The same habitat was also favourable to *Nyctophilus* species, even though this genus uses other habitats, but was not in moorland. Moorland could be the least preferred habitat for all species. It does not support taller trees, except in scattered patches, and the sedge species which dominate the vegetation provide less foraging and refuge opportunities.

There is little evidence that Tasmanian vespertilionids partition landscape structures. The typical sympatric distribution pattern found by acoustic survey in my project is consistent with previous Tasmanian studies (Taylor *et al.*, 1987; Rounsevell *et al.*, 1991; Driessen & Mallick, 2003). Thus, the presence of bat species appears to be not influenced by landscape variability.

Distribution survey in this project was conducted mostly on a single night acoustic data sampling per site and the site chosen was isolated from others. It remains poorly understood how Tasmanian bats use landscape elements to commute within or navigate across areas. Single night surveys can reveal the presence of a number of species sites yet do not explicitly depict how they differentiate use of the area in terms of commuting, foraging, or roosting. Repeated surveys at an area of interest are needed to understand habitat use. Clarification of the areas used for roosting and hibernation would also be important information for conservation outcomes.

Most of the distribution data including this study was collected during the austral summer months, October to March. At least one bat species was observed at each site, confirming that bat activity is probably continuous in most places in the warmer months. During this period, differences in species compositions of particular areas are considered to be minor (Taylor & O'Neill, 1986; Duncan, 1995). However, to convey a fuller picture of their distribution and habitat use, it is highly desirable to conduct inventory surveys throughout the year, because seasonal changes in local distribution of species are documented in temperate bats (Lumsden *et al.*, 2002; Cryan, 2003). Moreover, the apparent distribution of a species can be influenced by gender. Roost requirements of female bats are more critical as energetic demands on them are more severe than for male bats, especially in peak lactation periods. For instance, lactating females may decrease their habitat range to minimise energy cost, maximising output towards offspring (Mills *et al*., 1996; Henry *et al*., 2002; Lumsden *et al.*, 2002). Species assemblage at a site thus could change over time.

It has long been suggested that Tasmanian bats are in decline due to additive losses of suitable habitats for them. Even though the fragmentation of mature and old forests appears to have negative influence on roosting opportunity, not all forestry practises necessary influence species in the same way (Grindal & Brigham, 1998). Experiments to understand the effects of habitat fragmentation are often confounded by small sample size (Bright, 1993). A full understanding of the State-wide distribution and relative abundance of species within various habitats is not yet achieved in Tasmania. More complete inventories are needed for adequate management planning is required in order to conserve the native fauna.

Species inventory created by this study can help greatly towards understanding the actual distribution of species, as well as species-specific habitat use. However, caution must be exercised when drawing inferences (Sherwin *et al.*, 2000; Ford *et al.*, 2005). In this project, all sites were pooled into categories with similar environment, especially vegetation type, to explore habitat effects upon bat communities. Logistic analysis of this type of information is certainly useful to predict species occurrences, to assist target area of conservation interest, yet does not explicitly describe true species distribution. Future studies are strongly recommended using systematic Anabat surveys in poorly sampled areas including south-west and north-east of Tasmania, in order to better define the distribution and habitat for native bats. It is particularly important to better understand the distribution of *N. sherrini*, which is the only endemic bat in Tasmania.

In this study static recording was employed to sample echolocation calls of bats. While active recording (i.e. a transact method with hand-held detectors) has been suggested as useful for species inventory survey (e.g. Walsh & Harris, 1996; Milne *et al.*, 2004; Ford *et al.*, 2005), it poses reliability questions in the data sampled. Because active recording can cover larger areas of interest, including larger scale landscapes in relatively short timeframes, less detectable species may not be observed or missed because transects normally continue for less than an hour per site (Ford *et al.*, 2005). Previous studies found Tasmanian bats along with the other temperate vespertilionids are most active within three hours from sunset (Taylor & O'Neill, 1988; Rhodes, 1996; Hayes, 1997). Milne *et al* (2004) compared species accumulation rate against recording length from the sunset and found that the rate grew rapidly in the first several hours then become gradual. The species accumulation rate is an important tool to estimate the minimum effort to complete species inventory and thus for leads to obtain data to determine distribution of species. Chapter 6 deals with the activity patterns of Tasmanian bats and the species accumulation rate in more detail.

Full understanding of the distribution and relative abundance of species must be taken into account for conservation planning. Several recommendations can be made from this study;

1) State-wide species inventory using Anabat systems, radiotelemetry and surveys on roost and hibernaculum requirements for species and the availability of those refuges would improve understanding of the full distribution of species.
2) Additional surveys should also be conducted during winter. Inada (2006) reported there can be a considerable amount of activity observed using Anabat detectors

during this period. Hibernation occupies approximately four to six month of the year, which makes the behaviour as important to be understood as summer activity.

3) Anabat call files should be archived and made accessible for future reference. Retrospective analysis on an archived files deposited from long-term monitoring of an area can reveal new distribution range of species, for example *Taphozous kapalgensis* was discovered this way in the Northern Territory (Milne *et al.*, 2003).
4) Prediction of species richness at local scales or potential distributions of species, measures of species' prey food types and their total abundance may not be adequate predictors (Rhodes, 1996). Milne *et al* (2005) found that insect availability was not significantly associated with bats assemblages in northern Australia. Many insectivorous bat species are suggested to be opportunistic feeders (e.g. O'Neill & Taylor, 1989; Milne *et al.*, 2005) and hence insect availability appears to hold less importance as a factor in the habitat selection of Tasmanian vespertilionids.

Generally species richness for most insect groups is higher in undisturbed forest habitats, yet overall abundance can be lower compared to cultivated areas, where pest species can be extremely abundant (Gorressen & Willing, 2004). This implies that some cultivated areas may offer increased opportunity to exploit food bonanzas but at the cost of less opportunity to select prey types. This type of feeding opportunity is particularly favourable to larger sized bats as they are able to capture a wider range of prey sizes whereas smaller species may only be able to exploit smaller sized insect due to their body sizes (Taylor & O'Neill, 1986). On the other hand, higher insect species richness may support a higher number of bat species by providing opportunity for them to take a wider range of insect prey.

Tasmanian caves generally maintain a temperature of around two degrees Celsius throughout the year, even in winter (Alistair Richardson, pers. comm.). This stable temperature just above freezing point during winter may seem to provide suitable hibernacula, but fluctuations in temperature are necessary for repeated arousal during hibernation especially where enough light does not penetrate underground and trigger arousal. Entering hibernation deep in cold caves would eventually cause death to those bats, consequently preventing colonisation of Tasmanian caves. In fact, Tasmanian cavers have found more dead bats on the cave floor than living ones (Arthur Clarke, pers. comm.). As there is no evidence to support cave dwelling in Tasmanian bats, mature forest is primarily the most important habitat for their refuges.

Chapter 6

The activity patterns of Tasmanian bats based on evidence from acoustic surveys

6.1 Introduction

The activity patterns of animals reflect the interplay between environmental and ecological processes which governs their lives. Survival in a fluctuating environment requires the evolution of strategies which synchronise daily and seasonal activity patterns with limited resource availability. These strategies are especially important at higher latitudes where microhabitat conditions can greatly fluctuate on both a daily and seasonal basis. Temperate zone insectivorous bats maintain their energy balance in a seasonally changing environment by compressing the annual reproductive effort into periods of optimal food availability in summer, and lowering energy costs by hibernating through the cold winter. In Tasmanian bats, hibernation is partly facultative as some degree of activity is necessary for the accumulation of energy stores to ensure survival during the winter period and successful reproductive processes.

Nightly activity patterns of bats can be influenced by a number of factors including prey abundance (Taylor & O'Neill, 1984; Ellis *et al.,* 1991; Rhodes, 1996; Hayes, 1997), the intensity of moonlight (Adams, 1997; Adams *et al.,* 2005; Welbergen, 2008), weather conditions (Ellis *et al,* 1991; Hayes, 1997; Agosta *et al.,* 2005) and energetic demands related to pregnancy (Lumsden *et al.,* 2002). Nightly foraging activity in temperate zone bats commonly displays a bimodal pattern in the spring to autumn period (O'Neill, 1984; Taylor & O'Neill, 1988; Hayes, 1997). Harp trapping of Tasmanian bats suggests that peak activity levels tend to occur in the first three hours after sunset, followed by a second peak in the three hours before sunrise which approximately corresponds to possible peaks in insect abundance (O'Neill, 1984; Taylor & O'Neill, 1988).

Forest-dwelling bats can be difficult to observe in terms of their emergence activity. Unlike cave-dwelling bats in North America and temperate Europe, Tasmanian

bats tend to roost as solitary individuals or in small sized colonies, except when in maternal roosts which can involve up to 60 bats (see Chapter 2). Nightly activity of bats is triggered by species-specific requirements that serve to optimise their energetic intake.

One issue concerning activity patterns of species is whether the behaviour in question is performed at random over time or whether it is non-randomly structured (Speakman *et al.,* 1999). Theory predicts that coexisting species should differ in their use of resources to avoid competition over the same resource. Partitioning of resources, especially food, could be important in eastern Tasmanian where nearly all species co-habitat, despite diets considerably overlapping. Understanding the temporal aspects of species activity and their variations has drawn the attention of a number of researchers, as it reflects important spontaneous responses of bats. Studies on the temporal aspect of activity have included the emergence timing in relation to sunset/sunrise (Richards, 2001; Milne *et al*., 2006), hourly variation in amount of activity (Taylor & O'Neill, 1988; Hayes, 1997; Law *et al.,* 1998; Agosta *et al.,* 2005) and seasonal change in activity pattern (LaVal *et al.,* 1977; Avery, 1985; Taylor & Savva, 1990; Ellis *et al.,* 1991). Temporal questions can be examined by using an index of activity assigned to the predefined times scales (i.e. intervals measured in hours or proportions of night length).

The most important limitation of echolocation methods is that data collected by bat detectors does not allow an accurate estimate of population abundance. Acoustic recording provides no more than a relative index of activity because there is no one-to-one correlation between bat passes and the number of individuals presented (Thomas & La Val, 1988). For instance, ten call records on a night can be obtained from a single bat passing ten times or could represent a single pass from 10 individuals. For this reason an absolute abundance of species at site cannot be estimated from the data. This is particularly a problem when the primary interest of the study is to compare the relative abundance of species among different habitats However, this approach can provide relative estimates of activity patterns of bats and their usage of habitats of interest via an activity index (Hayes, 1997; Humes *et al*., 1999). Once reliable species identification is possible from the echolocation data, activity patterns of each species recorded at the same time can be compared. Another advantage of the static echolocation method is that it does not adversely affect bat activity at a site, whereas harp-trapping has been demonstrated to lead to a significant decrease in capture rate on subsequent nights (Taylor & O'Neill, 1988). Bats seem to quickly learn the locations of physical obstacles (e.g. traps in the flyway) and consequently find ways to avoid them

(R. Taylor, pers. comm.), resulting in the necessity to relocate harp traps regularly. This is another advantage of echolocation methods when limited time is available to prepare a species inventory for a site.

There is little doubt that the acoustic recording survey method is an effective and efficient means of bat sampling in the field especially when the activity pattern of a species is of particular interest. To date, there have been published three surveys conducted with acoustic data sampling in Tasmania (Taylor & Comfort, 1993; Duncan, 1995; Rhodes, 1996). However, no study yet describes the species accumulation rate overnight.

In this chapter, the aims were to examine the temporal patterns of nightly activities of Tasmanian bat species. It is hypothesised that:

(i) sympatric bat species in Tasmania will differ in their temporal activity patterns during the night to avoid competitive displacement, and

(ii) if this is true, each species should illustrate species-specific patterns of activity across nights when microclimatic conditions are favourable for activities involving commuting and foraging. In this sense, the timing of the first and the last emergences/calls should be closely located in order to optimise feeding opportunity.

In describing the temporal activity patterns of Tasmanian vespertilionid bats, species accumulation curves were examined. Creating a comprehensive inventory of species in minimal time using minimal effort is an important object for most bat surveys (Moreno & Halffter, 2000; Milne *et al.,* 2004). However, there are only a few studies (e.g. Richards, 2001; Milne *et al*., 2004) that have reported species-time relationships in terms of the accumulation rate of detected species using the Anabat system. Tropical bats tend to emerge sooner after sunset than temperate species (Richards, 2001; Milne *et al.*, 2004; Welbergen, 2008).

6.2 Methods

6.2.1 Data sampling, sites, and variables

Activity patterns were extracted from recordings covering at least 90% of night length, on multiple nights. Bat calls were sampled at communal sites (i.e. flyways) and other habitat usages were excluded from comparisons of temporal activity patterns (Fischer *et al.*, 2009). Three sites were chosen on the basis of the above criteria: Old Farm Road (OFR, N=8), Pipeline Track (PLT, N=6), and Thomas Crawford reserve (TC, N=3). In

addition to the recording period criteria, sampling was conducted at all three sites in close proximity to the entrance of flyways and less than 50 metres from open areas.

Nightly fluctuation in weather conditions including ambient temperature and relative humidity are known to affect temperate bat activity (e.g. Hays, 1997; Law & Chidel, 2006). Therefore weather variables were recorded at each site at the start of observations and related to the mean activity index for each species, and the species richness per night, using Spearman's correlation. Ambient temperature at set up ranged 11.1℃ to 20.5℃, while relative humidity ranged between 34.9% and 86.1%. Average wind speed and cloud cover, varied between 0.0 m/s and 1.7 m/s and 0% and 100% respectively. The activity index and the number of species at night were not significantly correlated with any measured weather conditions, indicating the survey was conducted under favourable conditions for the local bat species and hence the data is suitable to explore species activity patterns.

The nightly activity index for each species and the species richness were also checked against the moon phase to explore the effect of lunar phobic behaviour (e.g. Rhodes, 1996; Gannon & Willing, 1997; Elongovan & Marimuthu, 2001). Moon phase, in intervals of a quarter, was obtained from a moon calendar (Australian Fishery Management Authority, 2007; 2008; 2009). Each sampling night was assigned to one of four phases if it was within three nights of that particular phase. The activity index of species and the species richness recorded per night did not differ significantly in relation to the moon phase ($p > 0.05$ for each species and $p = 0.7$ for species richness).

Although previous studies suggested that monthly variation in the activity level of bats over the warmer months (i.e. October to February) may be negligible (Taylor & O'Neill, 1988; Duncan, 1995), any differences related to the seasonal change in night length were checked. Night length was determined by counting the minutes between sunset and sunrise. These temporal reference points (i.e. sunset and sunrise) were calculated using Anasun (Corben, 2001). There was no significant difference in night length among my observation nights ($p = 0.453$), yet the absolute maximum difference of night length was still considerable (mean = 660 ± 62.88 min). To assist comparisons, night length was therefore divided into 10 equal-time intervals for each night, between sunset and sunrise. In previous studies of Tasmanian bat activity, hourly divisions were used but one-tenth intervals are broadly equivalent to one hour interval, thus results should be comparable.

Activity indices were used to describe and compare the nightly activity patterns of bats. Each call recorded and identified to species level was assumed to represent an independent event and the aggregate of calls from a species should reflect activity

pattern as a whole. The activity index (AI) of a species was described by the number of calls recorded within defined time intervals. Counted calls for each species were assigned into each one-tenth interval for each night, and then summed together for the sites. Total activity index for a night was expressed as the sum of all AIs for all species on that night.

6.2.2 Analyses

Unidentified bat calls were excluded from further analyses in order to focus upon species-specific activities. Because the nightly AIs of bats were not normally distributed and contained a large number of zeros, a Chi squared test was used to examine difference of AIs between time intervals for each species. For time interval comparisons, AIs were compared between the first and second halves of night, and also at the 10 time intervals. For chi squared tests, the AI for each interval was transformed to a proportion of total AI for each species.

In exploring species activity patterns, the emergence time of each species as well as the rate of species-specific call accumulation were examined. First and last appearances by species were compared using a Kruskal-Wallis test to see whether species emergence timing differed between species. The rate of species-specific call accumulation was calculated. The time of sunset was used as a reference point for starting time. Half hour intervals since sunset were used in this analysis, instead of using proportional time intervals for other analyses (Richards, 2001; Milne *et al*., 2006). Because the number of species recorded varied between nights and sites, the first records of each species per night were aggregated and assigned to 30-min intervals from sunset. A mean percentage of the nightly total species tally was calculated for each interval to derive a mean species accumulation curve.

Statistical comparisons were not performed on AIs between species but some comparisons were made within species. The reason for this is that an activity index derived from bat detectors is not strictly comparable between species from several sites, while the intensity of echolocation differs among species and hence detectability of species differs. However, it is reasonable to compare indices between sites for the same species as long as the sensitivity of the detectors used (i.e. detector settings) is consistent (Thomas & La Val, 1988; Hayes, 1997). Chi squared tests on AIs between the intervals for species were conducted using Excel (Microsoft Co.) and JMP 7 (SAS Institute Inc) was used for other statistic analyses.

6.3 Results

A total of 2501 identified calls were useable within the complete dataset (Table 6.1).

Table 6.1 Number of identified calls from all site combined for species; unidentified calls were excluded from analysis.

Bat species	AI (No. of calls)
C. morio	530
F. tasmaniensis	75
Nyctophilus species	167
V. darlingtoni	348
V. regulus	902
V. vulturnus	479
Total	2501

Over all sites, the number of species observed each night varied between three and six. The timing of first and last appearance varied somewhat among nights within species but Kruskal-Wallis tests did not detect significant differences among species in both first and last appearances (p=0.17 and p=0.48, respectively). However, a number of generalisations can be made. First appearances of *V. regulus* were closely concentrated in the first hour from sunset, whereas the first appearances of *F. tasmaniensis* ranged substantially (Fig.6.1). For each species, the time of first emergence in relation to sunset varied among nights (Table 6.2). Because of the large standard deviation in this value for all species, median values were more useful to predict species activities in relation to sunset/sunrise. *C. morio, Nyctophilus* spp., *V. darlingtoni*, and *V. regulus* tend to appear earlier in the evening, around one hour from sunset. *C. morio* was generally the first species (48 minutes after sunset) to be detected among species in this study, while first detection of *F. tasmaniensis* was generally much later than other species (181.5 minutes after sunset). Time of last appearance of species was also variable between nights (Table 6.3).

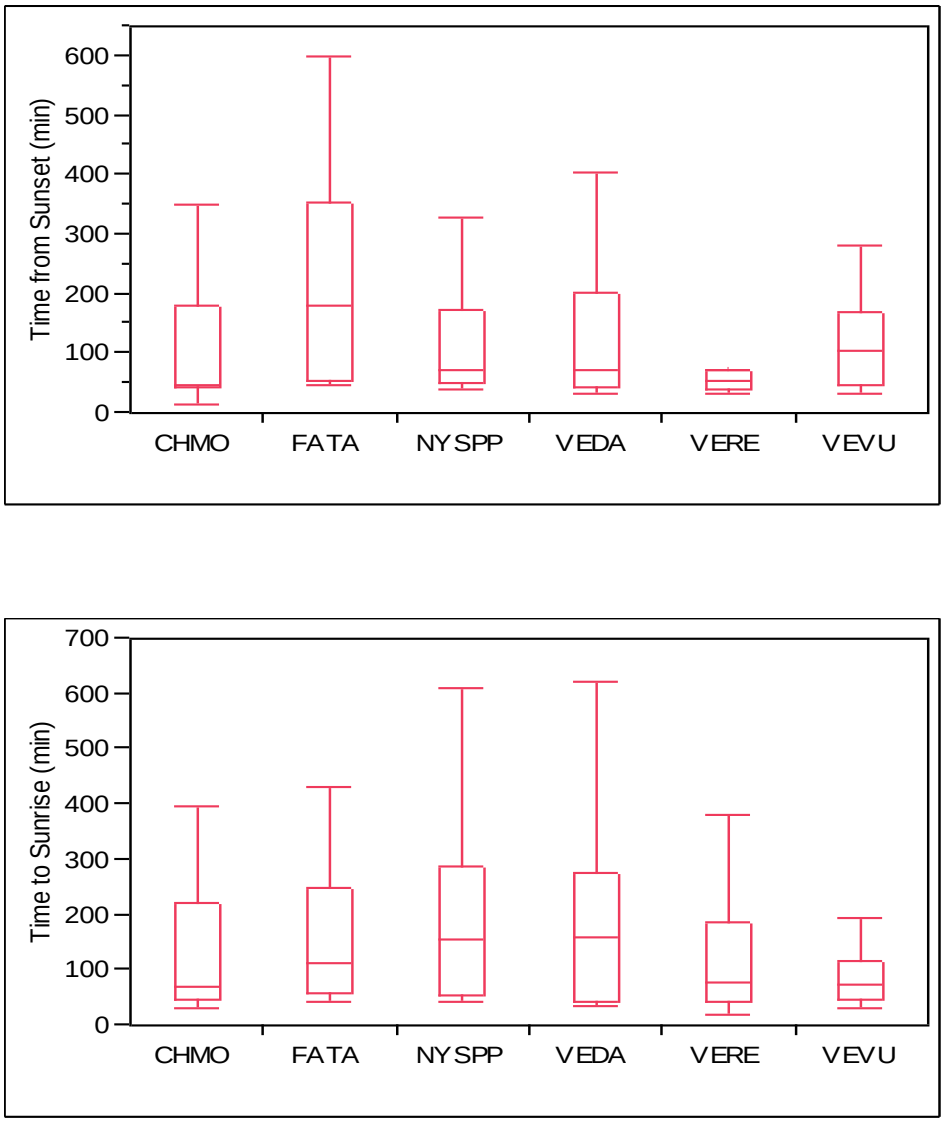


Figure 6.1 Box plots for timing of the first calls (above) and the last calls (below) for bat species.

Table 6.2 Timing of first calls of species in relation to sunset.

		Time of first call of night in minutes from sunset			
Bat species	No. of nights	Minimum	Maximum	Median	Mean ± SD
C. morio	15	14	498	48.00	137.07 ±165.92
F. tasmaniensis	8	47	599	181.50	223.13 ±196.08
Nyctophilus spp.	16	40	458	73.00	146.25 ±135.63
V. darlingtoni	15	32	405	71.00	120.73 ±117.88
V. regulus	17	32	267	54.00	76.00 ±62.62
V. vulturnus	17	34	368	103.00	121.82 ±93.74

Table 6.3 Timing of last calls of species in relation to sunrise.

		Time of last call of night in minutes before sunrise			
Species	No. of nights	Minimum	Maximum	Median	Mean ± SD
C. morio	15	30	396	69	132.66 ±117.28
F. tasmaniensis	8	44	432	114	158.50 ±133.29
Nyctophilus spp.	16	42	611	155.50	213.88 ±189.47
V. darlingtoni	15	36	623	160	194.20 ±182.08
V. regulus	17	20	440	76	132.71 ±126.21
V. vulturnus	17	32	615	75	115.77 ±136.92

The species accumulation curve for Tasmanian bats shows that the greatest rate of increase in the cumulative number of species detected occurred in the first three and half hours after sunset, when 80% of species were detected (Fig. 6.2). The first time block (i.e. within 30 minutes from sunset) did not record any species, except on one occasion involving *C. morio*. The accumulation rate then dramatically slowed to reach 90% nearly eight hours after sunset. The average time taken to record 100% of species was 10 hours from sunset.

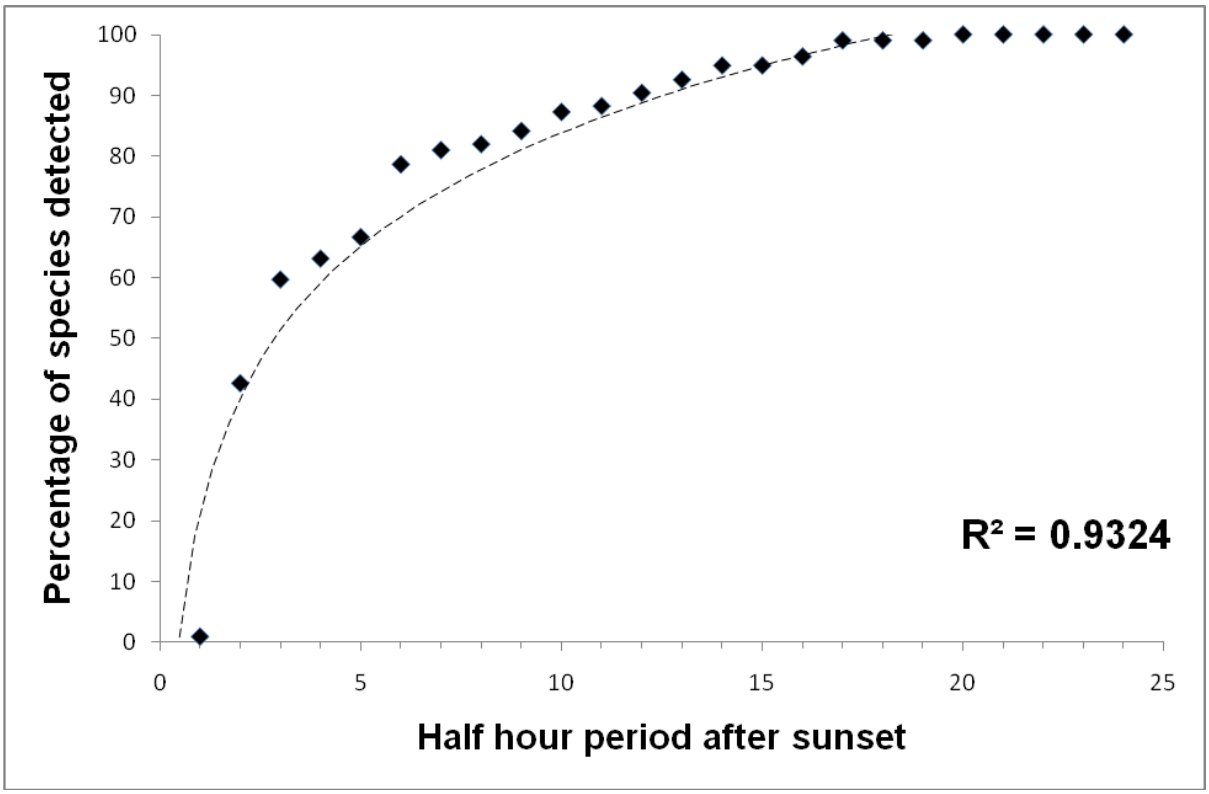


Figure 6.2 Bat species accumulation curve averaged over all sites using half-hourly increments after sunset. The points are fitted with a logarithmic regression.

No significant difference was found between the AIs in the half night comparison for most species ($p>0.05$) but *F. tasmaniensis* showed approximately 20% more activity in the second half of the night ($p < 0.01$) (Fig. 6.3).

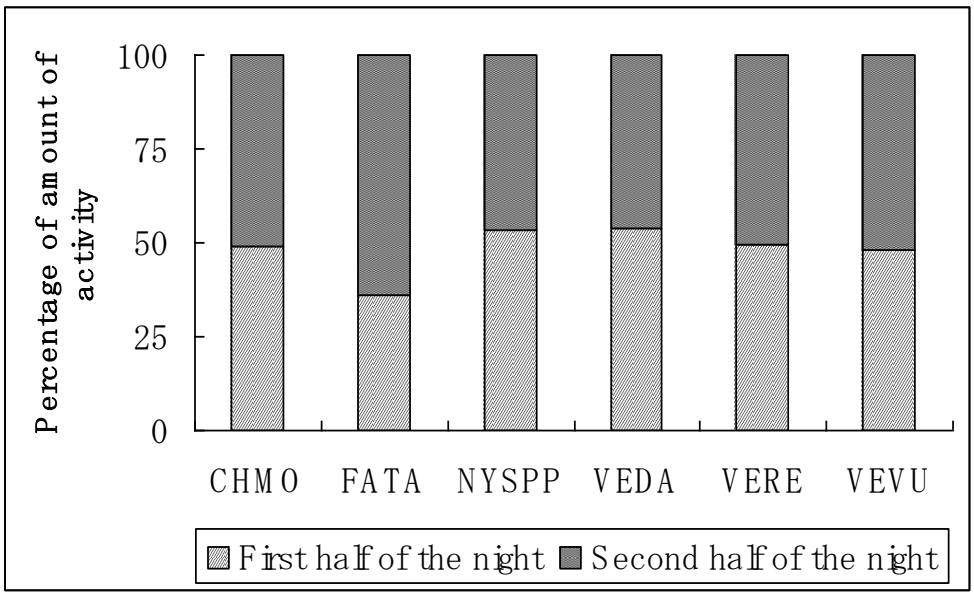


Figure 6.3 Proportion of AIs for species between first and second half of night

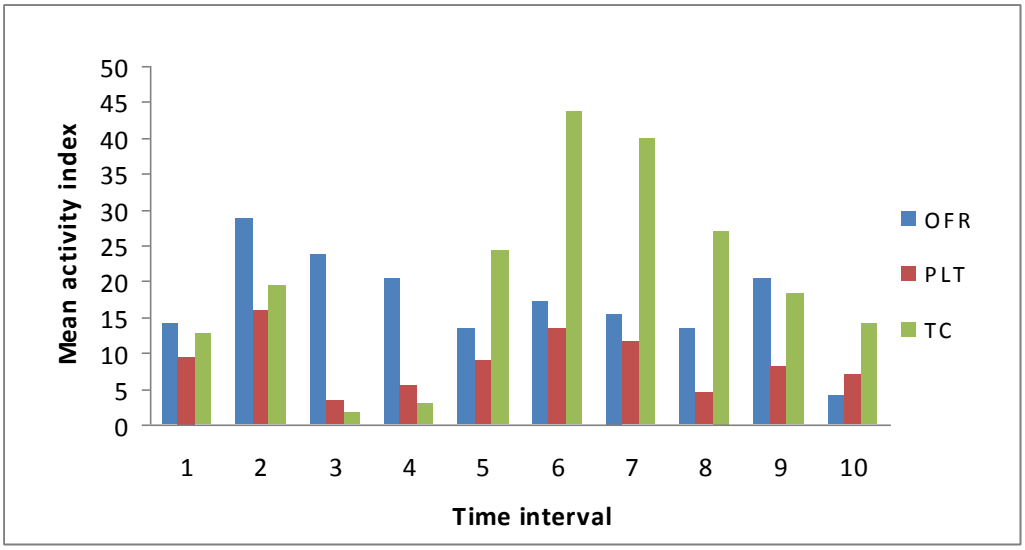


Figure 6.4 Mean activity index from three sites in one-tenth time intervals between sunset and sunrise, showing bimodal distribution of activity level.

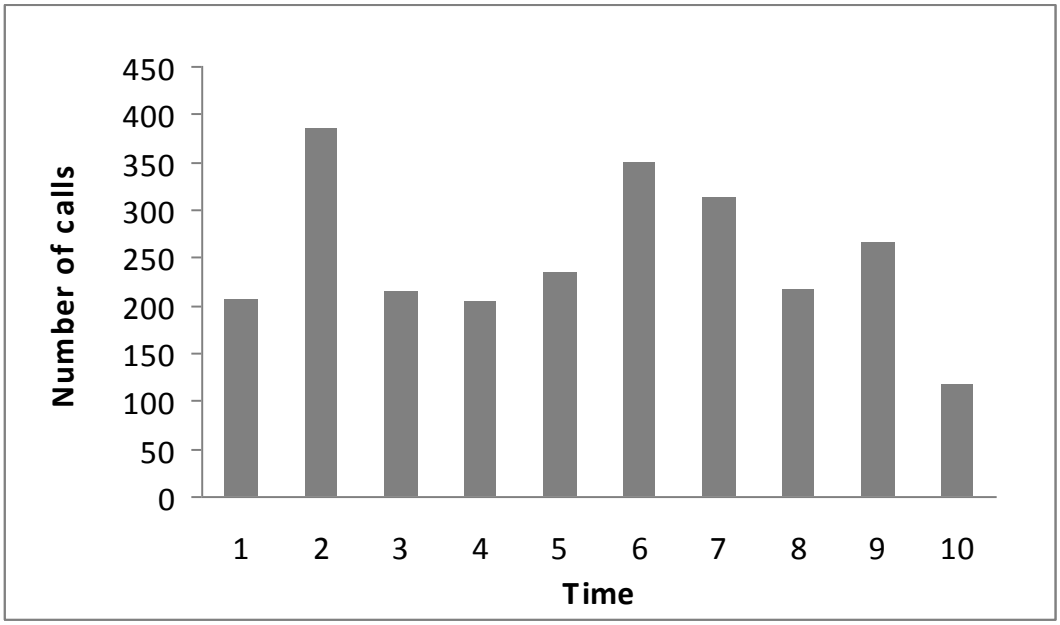


Figure 6.5 Overall activity distribution of Tasmanian bats in one-tenth time intervals between sunset and sunrise, all species combined.

The temporal distribution of activity (Figure 6.4) demonstrated a general bimodal pattern of activity across time intervals regardless of site. However, at sites

OFR and TC the peak activity contrasted. At site TC, more activity was observed at the second peak (around the sixth and seventh intervals), whereas at OFR the highest activity peak centred on the second interval later in the night.

The total bat activity index showed peak activity in the second interval of the night, followed by slightly lesser peaks at the sixth and then at the ninth intervals (Fig. 6.5). Overall night activity patterns of species are shown in Figure 6.6. Proportions of activity index differed significantly between the 10 equal-time intervals for the two species *Nyctophilus* species ($p=0.043$) and *F. tasmaniensis* ($p<0.01$) while other species showed small but non-significant differences. Identified taxa showed rather constant activity throughout the night. The least activity for all species was recorded in the tenth interval just before sunrise.

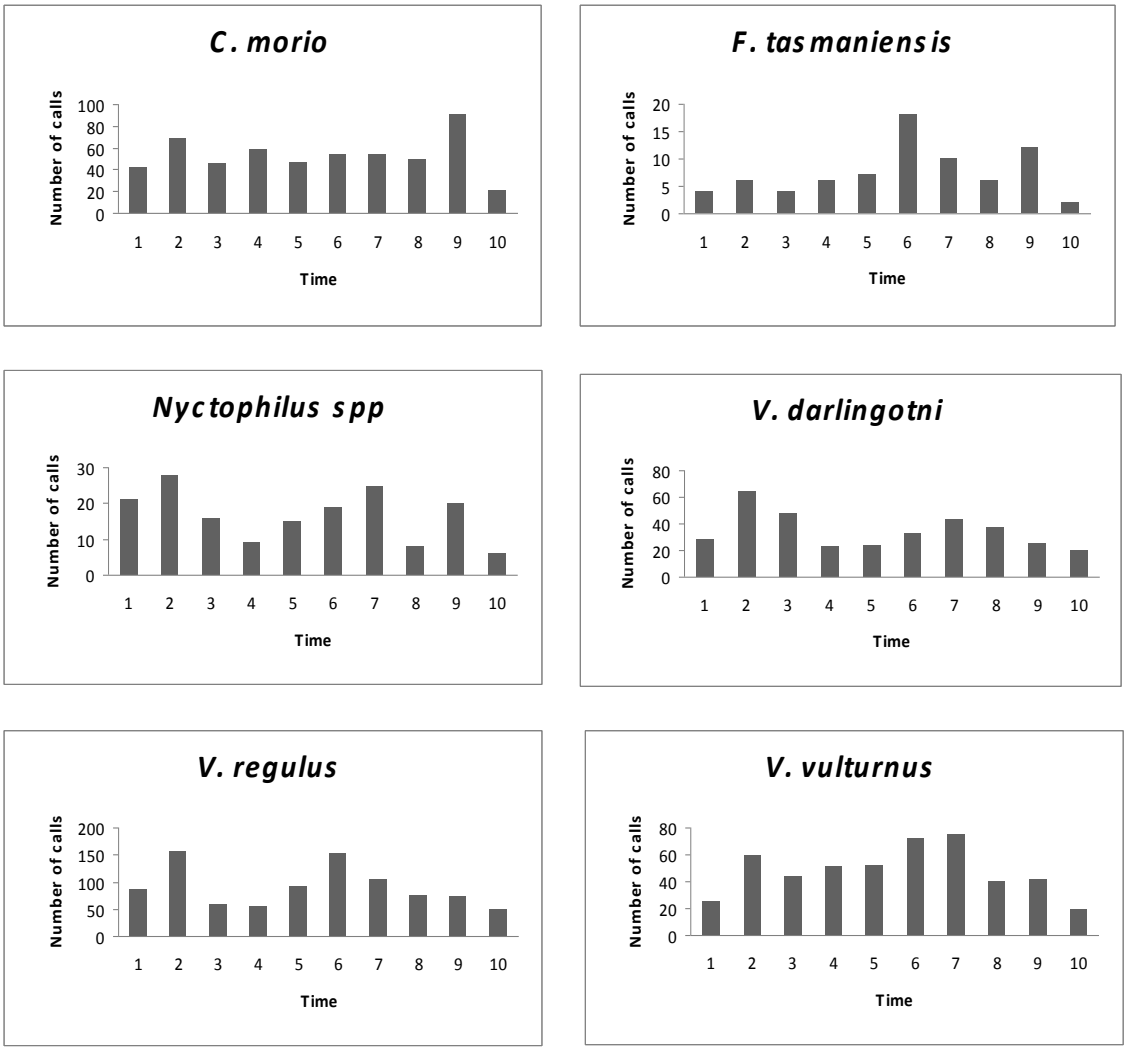


Figure 6.6 Activity patterns of all species through the night (all sites combined). Time scales are expressed as 10 equal-time intervals between sunset and sunrise.

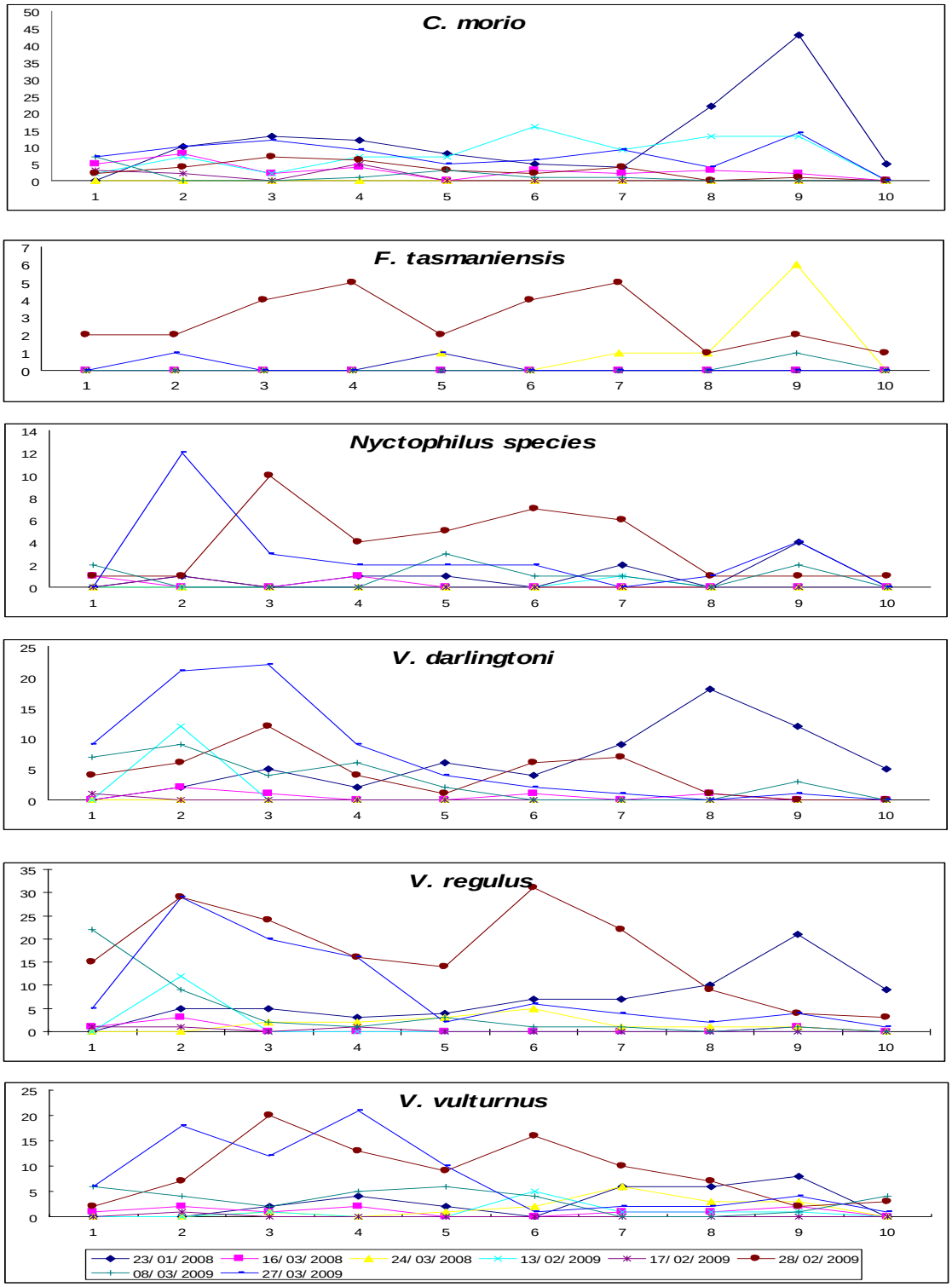


Figure 6.7 Nightly fluctuations of activity patterns for species recorded at OFR. Activity index against time interval. Time scales are 10 equal-time intervals between sunset and sunrise (n=8).

Even though the overall night activity patterns of species did not differ significantly throughout the night, fluctuations in activity pattern and activity index within species apparently changed on a night-to-night basis (Fig. 6.7). *C. morio* showed a consistently similar pattern among those nights at OFR corresponding to overall activity pattern. Although other species also commonly showed decreased activity index in the middle of the night, it was most apparent with *V. darlingtoni*.

6.4 Discussion

The number of active sympatric taxa varied between three to six species each night. At least three species of species were observed on any night and no significant correlation between activity index and local weather was found in preliminary analysis suggesting observations were conducted on suitable nights for survey and therefore the results can be claimed to reflect the general activity patterns for the species.

Forest-dwelling bats can be difficult to observe, however their activity period can be broadly estimated from the first and last appearance of a species each night. These results suggest that the timing of the activity period through the night slightly differs between species, although statistical significance was usually lacking The Eastern Falsistrelle, *F. tasmaniensis* would appear to have the minimum activity period of all Tasmanian bats. In contrast, *C. morio* and *V. regulus* have an activity period almost two hours longer. *V. regulus* was fairly consistent in being the first bat to appear each night, but the factor or factors responsible for this are not known. In this study, no local factors influencing the emergence of species could not be determined, but circadian rhythms or light intensity thresholds are known to trigger emergence activity for microbats elsewhere (Welbergen, 2008).

A few previous studies present species-time relationships derived from Anabat data collected in a similar manner to the present project (e.g. Milne *et al.*, 2004). For example, the first three hours of recording detected up to 70% of sympatric taxa in Victoria compared with 80% in the Top End of the Northern Territory, and 78.6% in Tasmania. In the present Tasmanian study, 91% were detected within six hours of sunset compared with between 75% and 90% in Victoria and 97% in the Top End. The species accumulation rate is an important tool when attempting to establish standards for bat fauna surveys for species inventory, because it allows to estimate a minimum sampling effort required to reach a satisfactory level of completeness (Moreno & Halffter, 2000). The accumulation curve for the Tasmanian bat community was more similar to that for

Victorian bats (Milne *et al.*, 2004) compared to the tropical bat community, taking a longer time to reach >80% cumulative rate for the night. Thus, echolocation data accumulated in less than three and half hours after sunset could be expected to miss more than 20% of species potentially present. This is particularly the case for *F. tasmaniensis*, which as well as being less detectable (being a high over-canopy flier), tends to emerge much later in the evening than other species. Furthermore, to assess the presence/absence of *F. tasmaniensis* at a site it would be necessary to conduct the survey all night. The accumulation curves also showed that to reach the maximum cumulative value took an average 10 hours recording per night. Between November and February in Tasmania the night length does not reach 10 hours (the minimum in late December is slightly less than six hours). There is a question regarding bias in species detection when night length varies strongly over the non-hibernation period. In my analysis several nights exceeded 10 hours duration and, in contrast, estimates of species richness in midsummer may need less recording minutes to accumulate a high percentage of species in the night. However, there has been no study describing the species accumulation rate in Tasmanian before, so this study may be seen as a foundation for estimating the minimum survey effort needed.

The near equal proportions in the activity index for each half of the night for most species support other evidence that most bats are rather constantly commuting or seeking feeding opportunities throughout the night. Only *F. tasmaniensis* demonstrated an activity level that was significantly greater in the second half of the night. The results suggest the pattern of activity in summer is less species-specific as statistical analysis did not find significant differences in time-related activity indices for most species. A broadly bimodal pattern in activity was apparent in *Nyctophilus* species, *V. darlingtoni* and *V. regulus*, while *C. morio* and *V. vulturnus* were more constantly active through the night.

The finding of this study offers several contradictions to previous studies. Firstly, my acoustic recording demonstrated that the activity index for species did not markedly decrease between the usual two activity peaks (O'Neill, 1984; Taylor & O'Neill, 1988). In fact *C. morio* and *V. vulturnus* appeared to sustain a high activity level through the whole night, except for the first and the last time intervals. For those species showing a bimodal pattern a greater amount of activity was usually concentrated over a relatively shorter period around the first peak and a gradual increase toward the second peak after the middle of the night followed by a gradual decrease towards dawn (Fig. 6.6). Secondly, the second peak observed in the previous studies was closer to the end of night, approximately three hours before sunrise (O'Neill, 1984; Taylor & O'Neill,

1988). However my data indicates that the second peak occurs earlier in the night, around the sixth and seventh time intervals. *F. tasmaniensis* showed its highest activity in the sixth interval and displayed a typically unimodal pattern. Late activity in this species was also identified by Taylor & O'Neill (1989) who only captured specimens eight to nine hours after dark. The highest peak was found later in the night in *C. morio* and *F. tasmaniensis*, which is in agreement with the harp trap data of Taylor & O'Neill (1989). Although I failed to find a significant difference in the activity index for *C. morio*, these two species may be partitioning the habitat by delaying their timing of activity relative to other species.

Although the overall distribution of the activity index through the night generally showed uni- or bimodal patterns, variability in the activity patterns was substantial. Fluctuation of activity is more prominent in the species associated with lower detection rates. Because of my study could not survey different sites concurrently, these fluctuation made site comparisons difficult (Hayes, 1997).

Most Tasmanian bats show bimodal activity patterns during summer when energy requirements are at a maximum due to the demands of lactation and spermatogenesis (Taylor & O'Neill, 1988). Departure from a bimodal pattern to a unimodal one has been suggested to be caused by seasonality and microclimatic conditions including heavy rain, which is thought to be correlated to insect activity, and hence feeding opportunity (Taylor & O'Neill, 1988). Near constant activity level during the night can be explained by their foraging behaviour. The primary purpose of nightly activity is for feeding and therefore the duration of activity and the distance travelled should be determined by optimal foraging theory (Pyke 1984). The peak activity shortly after sunset appeared to correlate with the highest abundance of arboreal insects and to insectivorous bats would be the optimal foraging period. The total biomass of airborne insects declines with the reduction in air temperature over the night time in Tasmania, although there are several species of moths and beetles that start flying after midnight during summer (P.B. McQuillan, pers. comm.). In south-eastern Australia, Lumsden *et al.* (2002) found that two species, *C. gouldii* and *N. geoffroyi*, used different habitats for roosting and foraging in spite of the higher energetic cost incurred by commuting relatively large distances. A large commuting distance means these species can obtain resources from multiple landscape elements, and this appears to be true for all Tasmanian bats. Insect assemblages may change across microhabitats, yet bat activity may not necessary correspond to specific types of insects as most bats appear to opportunistically pursue a wide variety of insect types available at the time of foraging (Rhodes, 1996). Barclay and Brigham (1994) found that bats do not discriminate prey

items at fine scales in terms of the shape and texture of the target, but rather in natural environments, the discrimination is based on the size of prey. Most bats do not have sufficient time to discriminate targets by preference in time to optimise energy intake. This claim is supported in this project as species were active throughout the night, indicating that bats fly over a longer duration to increase foraging opportunity. An inference from relatively undifferentiated activity patterns among species is that on most nights suitable for bat activity, prey abundance is sufficient to support optimal foraging.

Tasmanian bats are less likely to be influenced by moon phase especially towards and during the hibernal period. Arousal bout interval during hibernation for Tasmanian bats (3 to 25g) is about 4 to 14 days (Taylor *et al*., 1986; Inada, 2006), which is about half a moon cycle (*ca* 29.5 days). This means arousal bouts take place at least twice to seven times during one lunar cycle. With highly changeable weather conditions typical of Tasmania, it is nearly impossible to adjust their arousals to synchronise to a moon phase in an energetically efficient manner. For example, Reith (1982) found that moonlight does not substantially suppress the activities of bats in New Mexico, compared to Africa and India and concluded the smaller species like *M. yumanensis* may not be able to afford such inefficient behaviour. Tasmanian bats are expected to follow that trend being in a similar situation with other temperate insectivorous species that do not exhibit lunar phobia (Karlsson *et al.*, 2002).

In conclusion, most Tasmanian vespertilionids, like other bats in the temperate zone, show substantial temporal variations in their activities on a night-to-night basis. This makes it difficult to accurately demonstrate species-specific patterns in general and most species tend to have a similar activity profile during the night. *F. tasmaniensis* appeared to be the most selective species based on the timing of its peak activity, and its first and the last appearances (i.e. active period). Tasmanian bats are suggested to be opportunistic feeders selecting prey from that which is available at the time. Habitat use by bat species changes considerably between regions, as well as the commuting distance in a night (Law *et al.*, 1999; Lumsden *et al.*, 2002) suggesting activity patterns of temperate bats would be area/landscape-specific, rather than species based. The composition of species did not appear to influence activity patterns in this study as a high proportion of bat species was commonly observed on the same night.

To achieve a satisfactory inventory of bat species at a site, species accumulation needs to exceed 80% (Milne *et al.*, 2004), and the echolocation recording from sunset needs to occupy at least three and half hours during summer in Tasmania, if overnight recording is not be possible. It is particularly important to detect *F. tasmaniensis*, which

tend to emerge later than the other species and has a shorter active period. Ideally, bat survey in Tasmanian should sample the entire night as suggested for other regions (Jolly, 1997; Law *et al.*, 1998; Richards, 2001; Milne *et al*., 2004).

There are several limits to interpreting my results when comparing to other studies. Data was collected mainly during summer and hence seasonal variations in activity patterns are not known, although these should be taken into account (Moreno & Helffter, 2000). The identification rate of call files in the project was relatively high (>80% for all recorded calls), yet *C. gouldii* could not be identified with certainty. In addition the small sample size for *F. tasmaniensis* leads to less confidence in its recognition in the raw datasets. Increasing the confidence of identification by using a key derived from high quality reference calls should increase the species-accumulation rate.

At present there are no data to conclude how or whether temperate insectivorous bat communities partition resources to prevent competitive displacement in general (Findley, 1993; Brigham *et al.*, 1997). If the perception raised from this study that undifferentiated patterns in activity is generally true, then it follows that roosting/hibernating ecology may have more important roles in partitioning niches in those species than prey selection and nightly activity pattern (Taylor & Savva, 1988; Rhodes, 1996). High discrimination in choice of roost habitat has been reported in temperate vespertilionids in contrast to their mild differentiation of activity in foraging and general habitats (Taylor & Savva, 1988; Law *et al.*, 1999; Lumsden *et al.*, 2002). A more detailed examination of bat refuges in areas of sympatry should be a significant priority for further research in Tasmania.

Chapter 7

General conclusion: conservation and management implications

7.1 Introduction

Tasmania has a very high biodiversity and the conservation of native fauna is one of most urgent issues facing the state as Tasmania has among the highest numbers of listed threatened species of any state in Australia (National Forest Inventory, 2003). In Tasmania 31 native vertebrate species are forest-dependent, requiring forest habitat for at least part of their life cycle, and bat species make one quarter of this group (National Forest Inventory, 2003). Many biological and ecological aspects of bats make them particularly important components of biodiversity. Bats demonstrate considerable ecological variation among their taxa. Their communities span various higher trophic levels, can be species-rich, abundant, widespread, relatively easy to sample, and responsive to disturbance in a broadly predictable way (Medellin *et al.*, 2000). Consequently, bats can be useful indicators of a wide variety of disturbances. Despite their ecological importance, bats have been relatively neglected in conservation and environmental management schemes due to a lack of information (e.g. Arnett, 2003; Fenton, 2003).

The present study contributes new information on the current status of bats in terms of distribution, habitat use and temporal activity patterns, compares knowledge of Tasmanian vespertilionids derived from previous studies and also fills some information gaps in the understanding of our native fauna. This study did not focus on a particular species, but rather at the bat community level. This enabled the project to examine bat community-habitat relationships as a whole. An acoustic survey used in the project found it was a useful tool to collect activity information about bat species and their community. Examining the nightly prey-bat relationships can yield valuable information about species conservation and can help determine areas of potential habitat deterioration. Habitat alteration affects the ecological quality of an area. It is easy to

recognise loss of habitat and changes in landscape as these modifications are rather large, yet other more subtle processes can similarly degrade habitat quality. Ecological quality of a habitat can be understood as a productivity cascade, from primary producers to final consumers and cycled back again. Cryptic habitat deterioration decreases ecological quality, although the physical structure of the habitat may seem to be retained (Bontadina *et al.*, 2008).

Conservation decisions require some understanding of the influence of deterioration of bat habitats as well as the responses of bats towards disturbance (Gorresen & Willing, 2004). Particularly for the bat fauna, riparian vegetation is an important habitat where the highest species diversity in an area is observed, as well as linear vegetation structures such as hedgerows that connect different habitats providing bats with safer commuting routes (Russ & Montgomery, 2002; Russo & Jones, 2003). Solitary remnant patches within an altered landscape may not help bat communities to sustain local populations efficiently, whereas linear structures provide flyways from one habitat to the other and can increase the level of utilisation of such small remnant patches. The development of effective and efficient conservation planning and management should be based on understanding of ecological relationships, not only to responses to habitat fragmentation but other factors involving resource competition with invasive species and predator-prey relationships with other organisms that may influence species persistence. Conservation of species is much needed at local scales, as well as at landscape scales for community biodiversity conservation at the same time.

The latest example of a loss to the Australian mammal fauna occurred in 2009. The Christmas Island Pipistrelle, *Pipistrellus murrayi*, has been announced as possibly extinct after intensive searches, conservation and rescue programs were conducted (Lumsdem, 2009). An acute decline in the population of the Christmas Island Pipistrelle has been reported since 1994 and it took less than two decades to reach probable extinction (Campbell *et al.*, 2009).

In this chapter I present a summary of the findings of the current project and synthesis conservation implications and recommendations for future research that is needed.

7.2 Summary of findings

This chapter synthesises the main results from chapters 4 to 6, followed by a discussion on the implications for the conservation of Tasmanian bat fauna. The aims of the current

study were;

- Create an echolocation identification key based on reference calls obtained within the Tasmanian region
- Use acoustic methods to collect distribution records for as many species as possible
- Document and interpret the nightly activity patterns of species determined by echolocation survey

Chapter 4 aimed to create a regional identification key for Tasmanian species and a reference call library. The identification of echolocation calls emphasised objective quantitative methods rather than traditional qualitative approaches. Classification tree analysis and automated identification programs were applied. Echolocation identification of Tasmanian species was successful for several species including *C. morio*, and the three forest bats, *Vespadelus* species. These species were also abundant during harp-trapping sessions and supplementary call records were made available by other researchers (B. Law and L. Cawthen). Unfortunately, there were only a few individuals captured for *F. tasmaniensis* and *Nyctophilus* species, and none of *C. gouldii*. *Nyctophilu*s species demonstrated call patterns diagnostic at genus level, but the two individual species could not be separated on this evidence. *C. gouldii* seems to have a similar call pattern to mainland conspecifics (B. Law, pers. comm.), but failure to obtain any Tasmanian individual made it impossible to confirm this species in my data from free-flying individuals. *Vespadelus* species were relatively tractable to record high quality reference calls compared to other bat species especially *F. tasmaniensis* which was more agitated during transfer and handling. Larger species tended to become active and aggressive and emerge more quickly from torpor. Future work is needed to complete the regional echolocation identification key for Tasmania. The reference calls used for developing the regional echolocation key is included in the appendix as a digital file for the purpose of building a regional call library. The validity and utility of the identification key developed in this project still needs to be tested for within-state differences in calls. There is no knowledge of population regionalism for any bat species in Tasmania, and therefore the likelihood of small differences in calls is uncertain.

The distributions of species and composition were examined in Chapter 5. In Tasmania bat species distributions largely overlap, as well as activity patterns during the night. I conclude that the occurrence of any species in Tasmania is largely haphazard and there was a failure to detect a strong correlation between occurrence and simple

environmental factors. Persistence of a population in a particular area would be largely chance-dependent and is not confined by any definitive combination of limiting factors, at least during the summer months. Most habitat areas appear to support multiple species in an assemblage and support bat activity by providing sufficient insects as food through summer nights. Composition of species across sites did not change substantially, and was marked by the presence of three *Vespadelus* species and *C. morio* at nearly every site. *F. tasmaniensis* was the least detected species in this study and was also the case in previous research conducted in Tasmania (O'Neill, 1984; Taylor & Savva, 1987; Rhodes, 1996). Even though this species is a fast, high altitude flyer in the over-canopy niche, *F. tasmaniensis* appeared to be the least abundant among Tasmania's bat fauna.

The study did not detect significant differences in the temporal activity patterns through the night among species where partitioning might be expected. Previous studies suggest that Tasmanian bat communities may avoid resource competition through differences in diet types, microhabitat partitioning of foraging areas and differences in foraging strategies (O'Neill & Taylor, 1986; O'Neill & Taylor, 1989). The demonstrated similarity in the activity patterns between species at night suggests that resource partitioning might occur on selection of prey that are available at the time of bat activity, rather than either a temporal nor spatial basis.

In my study the results strongly indicate that the large scale habitat requirements and summer activity patterns for Tasmanian species largely overlap with one another. Relationships between types of insect availability at site and wing morphology in detail would be a worthwhile subject for future research in Tasmania. Factors identified as being influential on bat activity pattern, and the level of their influence, differs among studies, implying they might be area- and/or species-specific (Hayes, 1997). In this sense, influential factors appear to be area-specific rather than species-specific in Tasmania. Furthermore, the roosting requirements for Tasmanian bats and their winter ecology involving hibernaculum requirements remain unclear for all of species. An understanding of summer activity of bats does not alone adequately inform knowledge of distribution of Tasmanian bats.

Chapter 6 aimed to examine the temporal aspects of nightly activity patterns. Acoustic recording on free flying bats found substantial differences in detection rate among species. This can be interpreted in two ways – it could merely reflect differences in echolocation behaviour, or else reflect actual differences in abundance between species. However, in combination with previous studies on the same species, it can be inferred that species recorded less often are indeed less abundant across study sites.

O'Neill (1984) proposed that the Tasmanian vespertilionids did not partition

foraging habitat. Harp-trap sampling in his study, in combination with my project confirms the high degree of overlap in habitat use among Tasmanian bats over the majority of the state. Although my study used flyways to assess whole habitat use, there is little doubt that overlapping in habitat use occurs by sympatric species.

Sympatric species must differ in their use of common resources to permit co-existence, and in morphological variability may reflect ecological selection pressure (Kunz, 1973). Rhodes (1996) suggested wing morphology is the most limiting factor of habitat use by bat species, and thus partly determines their distribution. Morphological diversity in Tasmanian vespertilionids has been documented, but is relatively low compared to other regions where larger numbers of species coexist within the bat communities. Similarity and overlaps in ecological features in terms of distribution, habitat use, and activity pattern suggest that inter-specific competition in the Tasmanian fauna would have less importance compared to the relatively severe environmental conditions creating selective pressures in Tasmania.

7.3 Management and conservation implications for Tasmanian bats

If the conservation of native bats is to be effective, both large scale landscape features and small scale modifications of habitats must be taken into consideration when predicting the impacts of management practices (Warren *et al.*, 2000). Conservation objectives suggested by Taylor (1990) involved three components: suitable habitat being available for each species; ensuring the opportunity for species to reinvade logged areas as they redevelop suitable habitat; and maintaining genetic interchange between populations restricted to patches of retained old growth forest.

The acoustical survey in my study indicated that Tasmanian species appeared to not necessary respond to habitat diversity with species-specific criteria for commuting/foraging area. In turn the partition of habitat may rely upon night roost/hibernacula requirements. There is a roosting preference in old growth forests over younger regeneration forests documented in forest dwelling bats in temperate regions (Taylor & O'Neill, 1988; Thomas, 1988). Older stands support more roosting opportunities by providing tree hollows and similar structures which normally start forming after tree ages of several decades to over a hundred years. Conservation programs for Tasmanian bats should therefore protect their refuges as a primary objective.

There is little doubt that degradation of vegetation in terms of clearing and

fragmentation of habitat is the greatest threat to biodiversity (e.g. Taylor 1990; Gibbons *et al.,* 2002; Mickleburgh *et al.,* 2002; Lloyd *et al.,* 2006). Restoration of vegetation through selective logging and plantation development is commonly applied in Australia and Tasmania to maintain biodiversity. In many cases, however, the impacts of this treatment are not quantified (Law & Chidel, 2006), and estimations of the decline in population size, or the level of threat to the Tasmanian bat fauna from habitat degradation, is based on many assumptions few of which are examined in detail.

Not all forest activities necessary affect on bat community negatively. For example, removal of trees in small patches may in fact increase bat activity within the area as the insect assemblage can be increased (Grindal & Brigham, 1998; MacDonald, 2003). Temperate bats are able to utilise altered patches to forage and commute to other habitats. Tasmanian bats can utilise regrowth forests as suitable foraging areas, although none of the species is thought to permanently roost in those forests (Taylor & O'Neill, 1986; Taylor & Savva, 1988).

Temperate bats species tend to show relative high tolerance to habitat fragmentation in foraging areas (Bright, 1993). Relatively high tolerance to habitat deterioration is enabled high locomotive and flight ability allowing most bats to commute across mosaic habitats without difficulty. Moreover, vegetation corridors along riversides that connect to surrounding areas appear to have an important role in retaining bat species composition in the area (Russ & Montgomery, 2002; Milne *et al.*, 2005). Corridors provide commuting flyways as well as foraging habitat for some species as they attract insect activity. Impact-reduced forest activity has been demonstrated to better retain insect biodiversity than more conventional logging techniques in tropical rainforests (Davis, 2000). If wing morphology is the main constraint on habitat use by species in Tasmania (Rhodes, 1996), appropriate forest management may increase opportunities by providing both preferable prey and micro-habitats by creating extra edge area in the landscape.

The impacts of urbanisation on bats are expected to be largely similar to forest activities. The adverse impacts of urbanisation on bat fauna may be mitigated by maintaining trees, gardens and small patches of cultivated land. If suitable roost habitat were sustained, urbanised areas can be suitable habitats for some species where street lights accumulate flying insects (Russo & Jones, 2003; Rhodes, 2006; Scanlon & Petit, 2008)

Responses to habitat deterioration are different for each animal. Temperate bats are generally thought to be generalists in terms of dietary and habitat selection. As well they have higher dispersal rates and higher mobility than many other terrestrial

mammals. This might suggest that bats are theoretically tolerant of habitat fragmentation and are predicted to exploit new habitats. On the other hand, Bright (1993) concluded that most of British bat species are more likely to be adversely affected by habitat fragmentation in the longer term. This is because British bats have low population densities, low reproductive rates, and the vulnerability of their roosts. Direct disturbance to refuge habitats (i.e. reduction of roosts/hibernaculum trees) could have a severe impact. Roost sites in tree cavities are difficult to locate for forest-dwelling bats with solitary roosting behaviour, and consequently knowledge of the roosting requirements for Tasmanian bats is very limited. Species-specific requirements for roost/hibernacula and seasonal changes in home range sizes are the most important questions to be addressed for Tasmanian vespertilionids and those can only be accomplished by radiotelemetry.

For any animal, suitable habitat area comprises two essential components; foraging area and refuge. Taylor and Savva (1988) found that average distances between night roosts for Tasmanian species are approximately 1 to 2.3km and they more often stay within that range. If this is true, retaining of suitable objects for roosting opportunity within the conservation target area is vital. Roosting habitat and foraging habitat are equally important. Acoustic survey can only help to document activity patterns and generate a relative activity index. High feeding activity levels in an area do not mean that the area provides roosting opportunities as such. Tasmanian bats use forest trees as roosts/hibernaculum almost exclusively, so the preservation of suitable forest habitats is important.

In Tasmania, research on bat communities has been conducted rather haphazardly. Monitoring of population or community structures in the context of known environmental change, including anthropogenic disturbance, can provide a basis for improved management decision making (Medellin *et al.*, 2000). Long-term monitoring is required to assure the quality of habitat and is requiring considerable amount of logistic and resources. Establishing long-term monitoring programs to track changes in the local bat fauna in terms of distribution, assemblage and population is needed, so that changes can be identified, assessed and utilised for appropriate management planning effectively for conservation of diversity of the bat fauna, but also the larger ecosystem. In particular, the recent recognition of a new species of *Nyctophilus*, *N. sherrini*, (previously regarded as a subspecies of the widespread *N. timoriensis)*, revealed that the species is endemic to Tasmania (Parnaby, 2009). The conservation status of the species is unclear and it is necessary to undertake more survey work to obtain this basic information. It remains uncertain if *N. gouldi* occurs in Tasmania. Both this species and

N. sherrini have similar external features and similar habitat use, and misidentification of the species may be occurred in previous studies in which identification was based on external features to distinguish it from *N. geoffroyi*. From a biodiversity conservation stand point, it is necessary to confirm species in the state and developing a state-wide species inventory is an urgent issue.

The general perception of bats among the public is often negative, which stems from an ignorance of their biology, ecology and the important role they play in local ecosystems (Mickleburgh *et al*., 2002). This attitude can be improved through better education, acknowledging scientific knowledge on biology, ecology and bats' role in native ecosystems. It can be provided to various sectors such as forestry and mining, speleologists, farmers and the tourist industry.

7.4 Future directions

Sampling data by bat detectors has a considerable advantages; relatively easy to recording a number of nights, setup remotely, and unattended. It can be only invaluable when inherent limitations and assumptions associated with acoustical recording and with type of detector used are articulated throughout the projects. For both conservation of Tasmanian native fauna or use bat species as indicator species to assess quality of habitats for management and conservation planning, more detail of bat species needed to be understood and further studies are required, particularly upon species distributions and differentials of habitat use. Limitations and assumptions must be addressed in each and all studies will be taken, and need to follow the standards of inferences and interpretations which comparability and repeatability make consistent.

Aforementioned in the previous chapters, acoustic recording techniques have several disadvantages and limitations in use, pointed out by a number of authors (e.g. Hayes, 2000; Gannon *et al.,* 2003; Fenton, 2003). In addition to general acoustic method limitations, there are detector-specific features which may affect sampling structures. For instance, zero-crossing period meter (i.e. Anabat) may have less sensitivity than other systems (Fenton *et al.,* 2001). However, upon comprehension of assumptions and limitations associated with acoustic survey methods, with articulated caution throughout research is still advantageous methodology of species distribution survey (e.g. Milne *et al.,* 2003; Law & Chidel, 2006) or long-term monitoring of temporal and spatial patterns to the current date (Hayes, 2000).

Upon understanding of those advantages and disadvantages, the finding allows

making several recommendations for future researches which will be beneficial to native bat conservation and their management planning complemented with previous studies;

1) Standardised acoustical survey methods, such as Anabat system in this study, should be more frequently implemented. Acoustical survey enables to sample data effectively over long period of time with less human logistic than other methods. This is especially effective where low amount of data has been collected and where complete species inventory of the area is needed. Acoustic sampling can also be implemented to measure relative activity in different habitats. In Tasmania, forest activity is the one of most concerned issues that impact on any native organism, yet other land used barely researched.

2) Indistinguishable habitat use and activity pattern of the species could indicate opportunistic requirement of activity habitats all species with large overlapping features. From conservation point of view, it is necessary to investigate day refuge over nightly activity.

3) The result suggests there is substantial difference of occurrence, or detectability, between species. *Vespadelus* species appeared to be commonly distributed and abundant along with *C. morio*. Meanwhile *F. tasmaniensis* had a considerably low rate of detection during the survey as well as any other study in Tasmania and Australia. Despite of its wide distribution along eastern Australia, *F. tasmaniensis* is one of least studied species. Small sample size made difficult to make deterministic conclusion for this species. In future research hence should more focus on *F. tasmaniensis* than other species to make quantitative evaluation. Aforementioned, *N. sherrini* is only species endemic to Tasmania, and much biology is about to discovered. Conservation planning will necessary to weigh these two species till their biology is fully understood.

4) Future study implementing acoustical survey on habitat use should include agriculture and urban landscapes. Many studies including the present study have more focus on bats activity in forest-related areas then totally open lands. Insectivorous bats are potential to be indicator species to evaluate habitat quality (Carmel & Safriel, 1998; Medellin *et al.,* 2000), quality of particular areas in question, such as organic versus other, can be evaluated. If habitat quality to be assessed in Tasmania, Vespadelus species are the suitable indicators for the task, because the use of the most abundant species in a given site as a disturbance indicator has important implications. The species are the most common and is easiest to detect, most likely to be represented from the start in any sample. On the other hand, representation of rarer species (i.e. *F. tasmaniensis*) in

sample is strongly stochastic and therefore hard to standardise through sampling effort (Medellin *et al.*, 2000).

5) Accumulation of data that collected similar manner can improve both understanding of bat biology and to be used for conservation and management planning of native fauna. If Anabat system is to be primary data sampling methods, the all call files should be retained and archived for future revisions, at least a call reference library should be created by authority to public access. Because at this stage, there is no reliable regional key available for Tasmanian bats, and refining the key needs accumulation of quality calls is only way to improve the reliability.

7.5 Conclusion

Species distributions along with environmental gradients in Tasmania could not clearly identified in the present study as species presence in different habitat was indistinguishable, and also that of activity patterns through the night. Climate changes along a longitudinal gradient are prominent in Tasmania, and a number of organisms are known to vary their compositions with the trend (Mesibov, 1994). Bat records in this study and others were mainly sampled in the Eastern regions, and few from western Tasmania. Creating a complete species inventory is necessary for conservation of biodiversity. Acoustic methods should implement acoustical monitoring in conjunction with harp-trapping to create complete species inventory, and determine state-wide species distributions. Systematic acoustic survey is much efficient if to be undertaken in poorly sampled areas such as south-west region of Tasmania. Further reference calls for all species needed to be collect, and tested regionally even within Tasmania. In this study, reference calls were obtained largely from relatively small area near Mt. Wellington supplemented with Warra region south east of Tasmanian. Validity of identification key needed to be tested regionality when sufficient reference calls accumulated. This is important in order to increase the effectiveness of surveys using echolocation techniques. The advance techniques combined statistical analyses and GIS which now commonly used in ecological studies can aid creating models for species distribution maps based on various factors.

Sustainability of biodiversity is an urgent issue to be addressed, and fundamental scientific knowledge is necessary to carry out and effective practical conservation and management planning. Tasmanian bats biology, ecology and roles in ecosystem are lot to be understood. I suggest implementation of effective data sampling methods in three

different approaches to achieve successful conservation and management planning. Roost availability and speciation of roosts would then appear to be the most important factor that determines the distribution of Tasmanian vespertilionids. Further researches on the species-specific roost requirements and their availability among habitat in larger scale survey are the most warranted. The future of native bats and their habitats will depend on policy decisions and management actions, which are determined based on rigorously collected scientific data. This project aimed to collect the basic data of Tasmanian bat fauna in order to supplement previous studies conducted in Tasmania. The data used here and analyses were exploratory, yet relationships with environmental gradients to species-specific responses were not clearly distinguishable in Tasmania. Understanding species-habitat relationship is critical for conservation of species as well as for diversity of Tasmania's unique fauna. In recent studies utilise GIS techniques to determine the habitat relation with bat species is increasing globally (e.g. Wang *et al.*, 2003; Greaves *et al.*, 2006; Milne *et al.*, 2006) and implementation of those techniques greatly improve understanding on Tasmanian bat conservation. The current study presented the current knowledge and status of Tasmanian bat fauna and implementation of acoustic survey methods would be useful for conservation of our native bats.

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Appendix i: gazetteer

Note a list is in order of field work date and a number of sites were repeated. Sunset and sunrise was calculated at the reference point (42°52’11”S, 147°19’41”E) by AnaSun (Corben, 2001).

Summer 2007-2008						
Date	**Site**	**South**	**East**	**Sunset**	**Sunrise**	**Night Length**
08/10/07	Thomas Crowford	42˚54'14.52"	147˚19'25.36"	19:24	6:34	11:10
24/10/07	Gould's country site 1	41˚15'51.14"	148˚01'24.30"	19:43	6:08	10:25
25/10/07	Gould's country site 2	41˚10'55.68"	148˚04'18.11"	19:44	6:06	10:22
01/11/07	Truganini	42˚55'46.40"	147˚21'02.49"	19:53	5:56	10:07
08/11/07	Mt. Wellington	42˚53'55"	147˚15'65"	20:03	5:47	9:44
10/11/07	Truganini	42˚55'46.40"	147˚21'02.49"	20:05	5:45	9:40
15/11/07	Queen's Domain	42˚51'42.70"	147˚19'10.31"	20:12	5:39	9:27

24/11/07	Mavista Nature Walk (Bruny Islnad)	42˚53'58"	147˚15'68"	20:23	5:32	9:09
24/11/07	Couley Rd Site (Bruny Island)	42˚53'59"	147˚15'69"	20:23	5:32	9:09
28/11/07	Alum's cliff (cliff edge)	41˚31'54.62"	146˚25'39.46"	20:28	5:30	9:02
28/11/07	Alum's cliff (bushtrack)	41˚32'02.67"	146˚25'46.24"	20:28	5:30	9:02
29/11/07	Lobster Fall (car park entrance)	41˚32'31.73"	146˚31'42.67"	20:29	5:29	9:00
29/11/07	Lobster Fall (rivulet)	41˚32'16.04"	146˚31'21.54"	20:29	5:29	9:00
05/12/07	Bridport (Streamside)	41˚00'55.74"	147˚23'30.47"	20:35	5:27	8:53
05/12/07	Bridport (Cattle field edge)	41˚00'57.15"	147˚23'30.96"	20:35	5:27	8:53
07/12/07	Thomas Crawford	42˚54'14.52"	147˚19'25.36"	20:37	5:27	8:50
15/12/07	Snug Tiers	43˚03'49.26"	147˚11'34.29"	20:44	5:27	8:43

24/12/07	Lost Fall FR	42˚02'26.15"	147˚53'17.20"	20:49	5:30	8:41
25/12/07	Sandpit	42˚42'24.71"	147˚50'29.38"	20:50	5:31	8:41
26/12/07	Prosser	42˚33'30.09"	147˚51'02.17"	20:50	5:32	8:42
03/01/08	Woodbridge Jetty	43˚09'35.92"	147˚14'32.37"	20:52	5:38	8:46
05/01/08	Edger dam	43˚01'54.41"	146˚20'58.24"	20:52	5:40	8:48
09/01/08	South Bruny NP (Bruny Island)	43˚27'39.76"	147˚08'42.85"	20:51	5:44	8:53
17/01/08	Lake Burbary old jetty	42˚04'18.37"	145˚38'36.65"	20:48	5:53	9:05
18/01/08	Collingwood River	42˚09'43.33"	145˚55'41.03"	20:47	5:54	9:07
19/01/08	Bronte Park	42˚08'09.86"	146˚29'40.57"	20:47	5:55	9:08
23/01/08	Old Farm Rd	42˚53'49"	147˚15'59"	20:44	6:02	9:18
26/01/08	Binalong Bay (Bay of Fire NCA)	41˚15'17.67"	148˚17'20.66"	20:41	6:04	9:23

27/01/08	Douglas-Aspley NP (Waterhole)	41˚51'53.4"	148˚11'11.9"	20:40	6:07	9:27
30/01/08	Woodbridge Jetty	43˚09'35.92"	147˚14'32.37"	20:38	6:10	9:32
02/02/08	Lime Bay SR	42˚57'30.9"	147˚42'11.6"	20:35	6:14	9:39
16/02/08	Esperance Forest Reserve	43˚18'00.7"	146˚54'34.8"	20:17	6:33	10:16
09/03/08	Pipeline Tracks	42˚55'15.8"	147˚15'31.9"	19:31	7:00	11:29
14/03/08	Mt.Wellington	42˚ 55'14.8"	147˚ 15'31.4"	19:33	7:07	11:34
15/03/08	Mt.Wellington	42˚ 55'19.6"	147˚ 15'33.3"	19:31	7:08	11:37
16/03/08	Old Farm	42˚ 53'44.4"	147˚ 16'03.2"	19:29	7:10	11:41
17/03/08	Old Farm	42˚ 53'44.3"	147˚ 16'04.1"	19:28	7:11	11:43
23/03/08	Mt.Wellington	42˚ 55'14.8"	147˚ 15'31.9"	19:17	7:18	12:01

24/03/08	Old Farm	42˚ 53'44.3"	147˚ 16'04.1"	19:15	7:19	12:04
29/03/08	Mt.Wellington	42˚ 55'14.8"	147˚ 15'31.9"	19:07	7:24	12:17
05/04/08	South Sisters (bottom)	41˚32'28.8"	148˚10'49.6"	18:55	7:31	12:36
05/04/08	South Sisters (top)	41˚32'04.2"	148˚10'28.3"	18:55	7:31	12:36
07/04/08	Fortescue Bay campsite	43˚08'35.8"	147˚57'42.8"	18:52	7:33	12:41

Summer 2008-2009

Date	Site	South	East	Sunset	Sunrise	Night Length
25/9/08	Thomas Crawford	42˚54'14.52"	147˚19'25.36"	18:11	5:55	11:44
12/10/08	Woodbridge	43˚09'35.92"	147˚14'32.37"	19:30	6:26	10:56
28/10/08	Sandford, Hollow tree	43˚00'15.6"	147˚28'37.4"	19:49	6:01	10:12

28/10/08	Sandford, Other tree	43˚00'15.6"	147˚28'37.4"	19:49	6:01	10:12
18/11/08	Olinda Grove	42˚54'36.79"	147˚19'02.69"	20:16	5:36	9:20
4/12/08	Gowrie Park	41˚28'32.93"	146˚12'57.58"	20:35	5:27	8:52
26/12/08	Thomas Crawford	42˚54'17.64"	147˚19'23.35"	20:50	5:32	8:42
14/1/09	Thomas Crawford	42˚54'15.31"	147˚19'24.02"	20:49	5:50	9:01
21/1/09	Pipe Line track	42˚55'15.8"	147˚15'31.9"	20:45	5:59	9:14
21/1/09	The Spring	42˚54'53.37"	147˚14'46.16"	20:45	5:59	9:14
13/2/09	Old Farm Rd	42˚53'49"	147˚15'59"	20:20	6:30	10:10
17/2/09	Old Farm Rd	42˚53'49"	147˚15'59"	20:14	6:35	10:21
22/2/09	Pipe Line track	42˚55'15.8"	147˚15'31.9"	20:07	6:42	10:35
28/2/09	Old Farm Road	42˚53'49"	147˚15'59"	19:57	6:49	10:52

8/3/09	Old Farm Road	42˚53'49"	147˚15'59"	19:44	6:56	11:15
18/3/09	Thomas Crawford	42˚54'14.52"	147˚19'25.36"	19:24	7:12	11:48
17/3/09	Pipe Line track	42˚55'15.8"	147˚15'31.9"	19:28	7:09	11:41
21/3/09	Truganini	42˚55'48.30"	147˚21'02.23"	19:21	7:14	11:53
21/3/09	Truganini	42˚55'49.36"	147˚21'11.55"	19:21	7:14	11:53
27/3/09	Old Farm Road	42˚53'49"	147˚15'59"	19:11	7:21	12:10

Appendix ii: Human health issues associated with bats

There have been a number of bat-related pathogens reported including viral, bacterial, protozoan and mycotic pathogens (Yalden & Morris, 1975). In Australia, three new zoonoses have been discovered since early 1990. Even though occurrences of such pathogens are rather sporadic and area-specific, sometime the threats are considerable in both human and bats communities. In this appendix brief accounts of health issues related to bats in Australia are presented.

Caves and Histoplasmosis:

Bat guano contains high percentage of nutrient and considerable amount of guano can be deposited in caves inhabited by large colonies of bat over years. High level of gaseous ammonia from guano deposit is fatal to human, yet bats tolerate to 100 times higher level. Histoplasmosis occurs in caves particularly in humid tropical region. Inhalation of toxic spore of a fungus, *Histoplasma capsulatum*, causes respiratory illness that rarely fatal to human. *H. capsulatum* is usually present in nutrient rich soil. Cavers and bat researchers who enters caves are at risk of inhale *H. capusualtum* spores. Sporadic events have been reported in New South Wales and other areas of Australia (Churchill, 1998; Churchill, 2008).

Hendra virus:

This virus was discovered in September, 1994, when 13 horses died in the Brisbane suburb of Hendra. So far Hendra virus has only occurred in Queensland, Australia. It is believed horses become infected by eating food contaminated by bat urine or birthing material. In humans, infection has been via exposure to the body fluids of dead or infected horses. The incubation period is up to 16 days and the initial symptoms include an influenza-like illness, fever and headache. These can progress to pneumonia, convulsions and coma. Hendra virus has killed four of the seven people known to have been infected in Queensland, the most recent in September 2009.

Along with the related Nipah virus from South Asian countries, Hendra virus appears to have originated from pteropid fruit bats. Even though outbreaks are rare, Hendra virus is classified as a bio-safety level 4 pathogens (Plowright *et al*., 2008). Nipah virus has caused many more human casualties and infects pigs also. The average mortality rate of the most recent outbreaks was approximately 70% and killed over 200 people, along with the culling of over one million pigs in Malaysia, Singapore, Bangladesh and India (Churchill, 2008).

The mode of transmission of Hendra/Nipah virus is suggested to be via bat urine.

Menagle virus:

Second unrecorded virus found in Sydney, 1997. Menagle virus caused two piggery workers melanise. Unlike other paramyxoviruses, there are antibodies and those infected people recovered. Flying foxes seem to be natural hosts and reservoir and the virus can be passed to pigs, which will result pregnancy problems, and then can be transmitted to human (Churchill, 2008).

Rabies and Lyssavirus:

Rabies and Australian Bat Lyssavirus (ABLV) is the same strand of virus and first separated in 1996. (Australian bat lyssavirus = serotype 7 and rabies = serotype 1). This is only zoonosis known to be directly transmitted from bat to human in Australia.

Rabies is considered to be the most dangerous hazard associated with bats in the world. Although it is rather rare instance that bats carry rabies in Australia like many other temperate countries (Fenton, 2003), a numbers of people have died infecting rabies by handling bats. Rabies is transmitted by transferring body fluids such as getting bitten or treating bleeding animals. In Central and South America where rare sungagevours predominantly feed on cattle, bat-transmitted rabies damages a very large number of livestock. Vampires may be the worst carriers, but any other bats can also carry the virus. Yalden & Morris (1975) reported 26 out of 40 species had detected rabies in USA, and most of bat handlers died infection was treating insectivorous bats. In Australia, two people have been died of ABLV, victims were bitten by bats while handling a flying fox and an insectivorous bat (Churchill, 2008).

Risks of zoonoses infection can be avoided, or at least mitigated, through adequate preparation and simple procedures, and these were kept reminded during the course of the study:

- Only touch animals if it is absolutely necessary, and have a pre-exposure vaccination
- Avoid direct contact with wild animals, using gloves when handling
- Observe of animals before handle them, if any unusual behaviour is apparent do not touch
- Wash hands and arms with soap/disinfectant after handling
- If get bitten, wash wounds with soap immediately and consult with doctors for infection and post-vaccination
- When examining roosts, best wear masks to avoid inhale pathogenic spores

Cave dwellers are more vulnerable to transmittable diseases as aggregation make transmit easier within the population. However, forest dwelling species such as Tasmanian bats still colonial at some stage of the life and no less vulnerable. Human induced transfer of fatal disease could lead irremediable damage to local populations. Recent discovery of the White Nose Syndrome in Northeast U.S.A. is the one of those, eliminating numerous hibernating cave bats. In some caves 90-100% populations were died. The disease is apparently caused by infection of cold-loving fungus, but it is unclear that a fungus is actual causation of death or secondary symptom of other factors, further research is still undertaking (US Fish and Wildlife Service, 2009; USGS National Wildlife Health Centre, 2009).

Appendix iii: Echolocation call features for the regional key for Tasmanian bat species

All call attributes were extracted from reference calls by Anasheme, and only attributes that were used to develop the key were shown with the mean values ± SD. Each attribute unit directly measured from call files were indicated in parentheses, others were calculated by the program. For details of attribute extraction methods and descriptions refer to Gibson and Lumsden (2003). *C. Gouldii* call features were not included.

Call attributes	**Species**					
	C. morio	***F. tasmaniensis***	***Nyctophilus* species**	***V. darlingtoni***	***V. regulus***	***V. vulturnus***
No. of reference calls	12	2	3	21	10	8
No. of pulses used	37	8	34	1026	509	282
Model curvature	3.066±0.984	1.821±0.760	1.320 ±0.289	3.657 ±1.484	3.891 ±1.548	3.361 ±1.519
Duration (ms)	3.283±1.151	2.142±1.059	2.228 ±1.122	5.318 ±2.492	4.227 ±1.856	2.834 ±1.497
Average time between pulses (ms)	86.890±20.003	8.025±1.993	69.154 ±21.458	59.379 ±41.703	38.634 ±26.336	63.546 ±33.823
End frequency (kHz)	45.755±1.839	30.561±11.267	39.965 ±5.605	43.511 ±1.801	44.594 ±2.145	47.828 ±2.287
Minimum frequency (kHz)	45.695±1.805	30.545±11.288	39.899 ±5.656	43.296 ±1.798	44.344 ±2.120	47.612 ±2.422
Maximum frequency (kHz)	58.795±9.661	41.658±13.811	64.884 ±12.323	60.273 ±13.387	64.751 ±11.378	63.875 ±13.704
Model frequency (kHz)	46.345±1.670	30.767±11.380	40.408 ±5.354	43.870 ±1.689	45.115 ±1.935	48.103 ±2.419
Model average frequency (kHz)	49.056±2.668	34.866±12.251	50.791 ±6.755	47.347 ±3.795	49.047 ±3.218	51.825 ±4.756
Model slope	0.782±1.330	4.912±4.927	9.763 ±5.768	0.625 ±1.559	0.896 ±2.018	2.901 ±4.522
Model end slope	-1.057±1.038	-4.329±3.952	-9.764 ±5.461	-0.944 ±1.286	-1.183 ±1.543	-2.517 ±3.254
Model start slope	-6.317±4.106	-8.078±5.962	-13.238 ±4.571	-6.190 ±4.694	-8.862 ±4.671	-11.075 ±8.120
Mean model frequency (kHz)	46.278±1.486	27.225±6.694	39.882 ±1.505	43.111 ±1.006	43.420 ±3.420	47.631 ±2.094
Mean model curvature	2.969±0.375	1.927±0.185	1.319 ±0.114	3.537 ±0.657	3.646 ±0.543	3.239 ±0.961
Mean model slope	0.922±0.511	3.318±0.025	9.425 ±4.129	0.911 ±0.613	1.032 ±0.644	3.027 ±2.368

Binary classification tree derived from above call characteristics by Weka ver. 3.7.0 (Witten & Frank, 2005). Below key was re-input to Anascheme after conversion to Python coding format.

```
average_time_between_pulses <= 57.238
|   mean_model_curvature <= 2.6667
|   |   mean_model_curvature <= 2.214
|   |   |   average_time_between_pulses <= 25.197: FATA (28.0)
|   |   |   average_time_between_pulses > 25.197: NYSPP (26.0)
|   |   mean_model_curvature > 2.214: VEVU (110.0)
|   mean_model_curvature > 2.6667
|   |   average_time_between_pulses <= 20.877: VERE (260.0)
|   |   average_time_between_pulses > 20.877
|   |   |   average_time_between_pulses <= 37.988
|   |   |   |   mean_model_curvature <= 2.8077: VERE (49.0)
|   |   |   |   mean_model_curvature > 2.8077
|   |   |   |   |   minimum_frequency <= 47.761: VEDA (704.0)
|   |   |   |   |   minimum_frequency > 47.761
|   |   |   |   |   |   average_time_between_pulses <= 32.483: VEDA (9.0)
|   |   |   |   |   |   average_time_between_pulses > 32.483: VEVU (43.0)
|   |   |   average_time_between_pulses > 37.988
|   |   |   |   mean_model_curvature <= 4.18: VERE (229.0)
|   |   |   |   mean_model_curvature > 4.18: VEVU (62.0)
average_time_between_pulses > 57.238
|   model_frequency <= 43.9398
|   |   model_slope <= 1.8894
|   |   |   mean_model_curvature <= 2.214: VERE (10.0)
|   |   |   mean_model_curvature > 2.214
```

| | | | model_frequency <= 43.0802: VEDA (299.0)

| | | | model_frequency > 43.0802

| | | | | mean_model_curvature <= 3.7747

| | | | | | mean_model_curvature <= 3.18

| | | | | | | mean_model_curvature <= 3: VEDA (11.0/1.0)

| | | | | | | mean_model_curvature > 3: CHMO (7.0)

| | | | | | mean_model_curvature > 3.18: VEDA (58.0)

| | | | | mean_model_curvature > 3.7747

| | | | | | average_time_between_pulses <= 99.464: VERE (16.0)

| | | | | | average_time_between_pulses > 99.464: VEDA (9.0)

| | model_slope > 1.8894: NYSPP (35.0)

| model_frequency > 43.9398

| | mean_model_curvature <= 3.75

| | | model_frequency <= 49.1068

| | | | average_time_between_pulses <= 100.975

| | | | | model_start_slope <= -2.9709

| | | | | | mean_model_curvature <= 3.3421: CHMO (435.0)

| | | | | | mean_model_curvature > 3.3421

| | | | | | | average_time_between_pulses <= 92.642: VEDA (8.0)

| | | | | | | average_time_between_pulses > 92.642: CHMO (52.0)

| | | | | model_start_slope > -2.9709

| | | | | | average_time_between_pulses <= 80.397: VEDA (16.0)

| | | | | | average_time_between_pulses > 80.397

| | | | | | | mean_model_curvature <= 3.6418: CHMO (72.0)

| | | | | | | mean_model_curvature > 3.6418: VEDA (2.0)

| | | | average_time_between_pulses > 100.975

| | | | | average_time_between_pulses <= 123.299

| | | | | | duration <= 2.572: VEDA (9.0)

| | | | | | duration > 2.572: VERE (14.0/1.0)

| | | | | average_time_between_pulses > 123.299: CHMO (41.0)

| | | model_frequency > 49.1068

| | | | average_time_between_pulses <= 73.92: CHMO (44.0)

| | | | average_time_between_pulses > 73.92

| | | | | average_time_between_pulses <= 89.872: VEVU (73.0)

| | | | | average_time_between_pulses > 89.872: CHMO (5.0)

| | mean_model_curvature > 3.75

| | | average_time_between_pulses <= 116.016: VEDA (27.0)

| | | average_time_between_pulses > 116.016: VEVU (42.0)

Appendix iv: Distribution records for species by echolocation identification

A summary of distribution records for sites from acoustic call recording. Present and absent is represented by 'X' and empty cell respectively. *C. gouldii* was not included. Total calls for multiple night recorded sites are mean value of all nights. For the record for Sandford is treated as one night site in analysis, but used two sets of detector within 200m distance thus herein counted as two night equivalent.

Site	No. of night	Total call	CHMO	FATA	NYSPP	VEDA	VERE	VEVU	Unknown	No. SPP
Alum's cliff (cliff edge)	1	180	X	X	X	X	X	X	X	6
Alum's cliff (bushtrack)	1	258	X		X	X	X	X	X	5
Binalong Bay	1	80	X			X	X	X	X	4
Bridport 1	1	110	X		X	X	X	X	X	5
Bridport 2	1	41	X		X		X	X	X	4
Bronte Park	1	381	X		X	X	X	X	X	5
Collingwood River	1	160	X		X	X	X	X	X	5
Couley Rd Site (Bruny Island)	1	84	X		X	X	X	X	X	5
Douglas-Aspley NP	1	108	X		X	X	X	X	X	5
Edger dam	1	187	X			X	X	X	X	4
Esperance Forest Reserve	1	313	X		X	X	X	X	X	5
Fortescue Bay campsite	1	78	X		X	X	X	X	X	5
Gould's country1	1	141	X		X	X	X	X	X	6
Gould's country2	1	321	X		X	X	X	X	X	5
Gowrie Park	1	348	X		X	X	X	X	X	5
Lake Burbary	1	134	X	X	X	X	X	X	X	6
Lime Bay	1	240	X		X	X	X	X	X	5
Lobster Fall (car park entrance)	1	48	X			X	X		X	3
Lobster Fall (rivulet)	1	179	X		X	X	X	X	X	5
Lost Fall	1	30	X			X	X	X	X	4
Mavista Nature Walk (Bruny Islnad)	1	7			X	X	X			3

Olinda Grove	1	104	X			X	X	X	X	4
Prosser River	1	299	X		X	X	X	X	X	5
Queen's Domain	1	3				X	X			2
Sandpit	1	52	X		X	X	X	X	X	5
Snug Tiers	1	38	X		X	X	X	X	X	5
South Bruny NP (Bruny Island)	1	18	X		X	X	X	X	X	5
South Sisters (bottom)	1	152	X	X	X	X	X	X	X	6
South Sisters (top)	1	30	X		X	X	X	X	X	5
The Spring	1	27	X			X	X	X	X	4
Old Farm Rd	9	180	X	X	X	X	X	X	X	6
Pipeline Tracks	8	86.62	X	X	X	X	X	X	X	6
Sandford	2	4			X	X	X	X	X	4
Thomas Crawford	6	120.17	X	X	X	X	X	X	X	6
Truganini	4	61.25	X		X	X	X	X	X	5
Woodbridge	3	150.67	X			X	X	X	X	4

Appendix v: Temporal distribution of the first calls for species

Time distribution of the first calls recorded for species in 30-min time interval through the night. Hyphen indicates the no first call was recorded in the time block. 13th to 24th periods are pooled together due to large number of zeros and small occurrences of first calls.

Species	No. of night recorded	Half hour block with first calls record												
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13 - 24th
C.morio	15	1	9	-	1	-	1	-	-	-	-	-	1	2
F.tasmaninensis	8	-	3	-	1	-	-	-	-	1	1	-	-	2
Nyctophilus species	16	-	5	4	-	1	3	-	-	-	-	1	-	2
V.darlingtoni	15	-	6	5	-	-	-	1	1	-	-	-	1	1
V.regulus	17	-	11	3	-	-	2	-	-	1	-	-	-	-
V.vulturnus	17	-	6	2	2	1	3	1	-	-	1	-	-	1
Total	17	1	40	14	4	2	9	2	1	2	2	1	2	8

Reference call library

This CD contains the reference calls of species used for the analyses of echolocation identification in the current project. A part of the study aimed to contribute to establish the reference call library for the Tasmanian bat fauna for the future research uses. The all reference call files are saved as Anabat 6 format. As the result, it is necessary to have at least Anabat 6 program to open the files. Analook w is highly recommended for a visual aid. Both program are freeware and can be downloaded from Chris Corben's website (www.hoarybat.com). Note that call files need to be saved onto the same drive with Anabat programs to visualise.

The identified calls saved in this CD are only those recorded under the current project. In the result, *C.morio, Cgouldii, N.geoffroyi, V.regulus* calls were not included.

I have also included three nights of raw call data from different sites for exploratory use. These files are saved on folders by nights named under the sites.

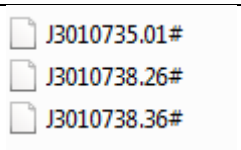
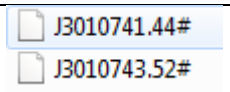
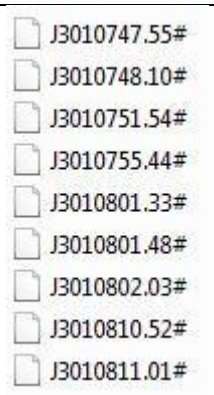
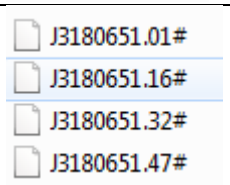
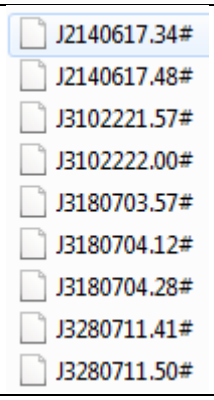
The CD also contains a key for echolocation identification for Tasmanian bat species as described in chapter 4. The key file can be viewed Microsoft notepad or other programs. To utilise the key, however, requires to installation of Anascheme (M. Gibson, unpubl. data, Ballarat University) and Python. To obtain Anascheme, please contact Mr Gibson at Ballarat University.

Added note for Library Open Repository thesis record

Schema of folder structure of data files

Files accompanying this thesis were provided on CD-ROM with the print version.
Files that have been copied here have been re-arranged from original folder structure into fewer folders to enable minimal number of .zip files. Tables below record the original folder structure.

1st folder	2nd folder	3rd folder	File names
TASbat raw calls	Old Farm Road	20090228	J2282020.30# - J3010613.46#
	Pipline Track	20090222	J2222056.50# - J2230405.11#
	Truganini	20090321	J3212034.58# - J3220648.49#

1st folder	2nd folder	File names
TASbat Reference Library	F. tasmaniensis	
	N.timoriensis	
	Unidentified (Vespadelus spp)	
	V.darlingtoni	
	V.vuluturnus	

A copy of the software required to read data files was also included with these files. Software version as available 29/8/14